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NAVIGATION.

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THEORY AND PRACTICE

OF

NAVIGATION.

BY

HENRY EVERS, LL.D.,

PROFESSOR OF MATHEMATICS AND APPLIED SCIENCE, PLYMOUTH.
AUTHOR OF "STEAM AND THE STEAM ENGINE," "NAUTICAL ASTRONOMY,"
ETC. ETC.

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PREFACE.

THIS book is intended to give beginners an insight into the simple theory and practice of Navigation. It has been the chief aim of the writer to make the subject as easy, practical, and perspicuous as possible, by omitting whatever is dry in theory, if not absolutely requisite, or likely to puzzle and confuse.

The author has keenly felt that a work of this kind was greatly wanted, and it has been his endeavour to supplement the design of the Publishers, in seeking to occupy a foremost place in supplying, in the best manner possible, the want so widely felt, so as to bring the Series of Text-Books, of which this volume forms one, within easy reach of every Student of Science in the Kingdom.

H. E.

January, 1873.

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NAVIGATION.

DEFINITIONS.

The science of conducting or taking a ship from one port to another is termed **Navigation.**

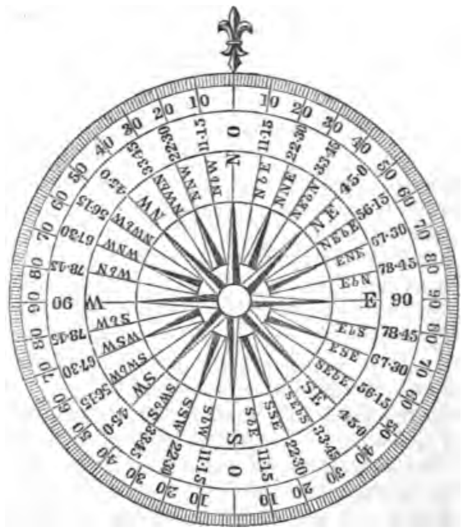
It consists of two parts : (1) *Theoretical*, or the science by which it is discovered in what track the ship must steer to arrive at any given place on the earth's surface ; (2) *Mechanical* or *Practical*, or the art of working, managing, or sailing a ship, so that it shall move in any given direction. It is the theoretical part only of navigation that will engage our attention in these pages.

Persons practising the science of navigation are called mariners or seamen. Mariners depend upon the directive force of the magnetism of the earth acting upon their compasses, to show them their way over the sea.

1. Compass.—A bar of hardened iron or steel, in the form of a long flat prism, or lozenge-shaped, has imparted to it magnetism, by the proper methods. When magnetised, and its centre pierced by a hole, into which is inserted a small agate, with a conical hole in it to receive the point of a small steel pin, it is suspended on this fine point, so as to be capable of free motion with the least possible amount of friction. The bar, after magnetisation, is found to possess the property of coming to rest only in one particular position, called the magnetic meridian, and thus always shows pretty nearly the *north* and south points of the horizon. The bar, called the

Needle, holds directive force of the mariner's compass; to it is attached the *card* on which is marked the rhumbs or points of the compass.

2. The **Card** is circular; its circumference is divided into 360 degrees and 32 points, to represent every different point of the horizon. First, it is divided into four



quadrants, by two diameters crossing each other at right angles; the ends of these two diameters represent the four cardinal points, N., S., E., and W. Each quadrant is divided into eight equal parts, making 32 divisions of the whole circle, which are called the points of the compass, or *rhumbs;* each point is frequently subdivided into half and quarter points. The point in the middle, between any two of the cardinal points, is expressed by the letters denoting these points: thus we have, going round from left to right, N.E., S.E., S.W., and N.W. The rhumbs half-way between these are named

according to their situation with respect to these middle rhumbs and nearest points; viz., going round the same way, N.N.E., E.N.E., E.S.E., S.S.E., S.S.W., W.S.W., W.N.W., and N.N.W.

Half-way between these several points, the points are indicated by the word *by;* the two nearest to N., on each side respectively, are named N. by E., and N. by W.; so those near E. are called E. by N., and E. by S. It will greatly assist the memory to be told that the first letter always indicates the precise point from which we must reckon.

N. by E.	means	one	point	from	N.	towards	E.
E. by N.	„		„	„	E.	„	N.
S.E. by S.	„		„	„	S.E.	„	S.
				or 3	points	from	S.
etc.				etc.			etc.

The mariner reckons all the directions in which his vessel sails, from the N. or S., and in points: for instance,

N.N.E.	he calls	2	points	right of N.,	not	6	points from the	E.
S.W. by S.	„	3	„	„ S.	„	5	„	W.
W.N.W.	„	6	„	left of N.	„	2	„	W.

It is essential that no mistake shall ever be made as regards *right* and *left.* Let the learner imagine himself standing in the centre of the compass, with his face towards the N., the E. is on his right hand, and W. on his left, so that a north-easterly course is always *right* of north, and north-westerly left of north; now face towards the S., when E. is on the *left,* and W. on the *right;* a south-easterly course being always left of south, and south-westerly right of south.

Every circle being divided into 360°, and there being 32 points to the compass, the angle contained between any two of them adjacent will be the $\frac{1}{32}$ part of $360° = \frac{360}{32} = 11° 15'$. So, therefore, the angle contained between the N. by W. rhumb and the meridian is 11° 15′, between the N.N.W. rhumb and the meridian, 22° 30′.

One-quarter of	a point	will be	2° 48′ 45″.
One-half	„	„	5° 37′ 30″.
Three-quarters	„	„	8° 26′ 15″.
One point	„	„	11° 15′ 0″.
Two points	„	„	22° 30′ 0″.
Three points	„	„	33° 45′ 0″.
Four points	„	„	45° 0′ 0″.
Five points	„	„	56° 15′ 0″.
Six points	„	„	67° 30′ 0″.
Seven points	„	„	78° 45′ 0″.
Eight points	„	„	90° 0′ 0″.

3. Course.—If a ship sail N. by W., the course is *one* point *left* of N.; if S.E., it is *four* points *left* of S.; if S.E. ½ S., it is *three and a half left* of S.; and if E. by S., the course is not *nine* points from N., nor *one* point from E., but *seven* points *left* of S. It should be mentioned, in order that the steersman may make as little mistake as possible regarding the direction in which he is ordered to steer, that inside the box in which the compass is placed, there is a vertical black line in the direction of the bow of the ship, called the **Lubber-line;** it is the duty of the helmsman to keep the point of the card, which indicates the compass course, always in contact or close to the lubber-line. If he is ordered to steer the ship S.E., he must move the helm so that at last the ship's head will come in that direction, or he moves his tiller, watching the compass until the lubber-line is close to S.E. in the compass box.

The card and needle are placed in a box covered with a glass face, and hung in a brass hoop upon two round pins, this hoop is hung within another brass circle, upon two brass pins diametrically opposite to the others, at a quadrant distant from each other, so that the card—however much the ship may pitch, roll, or heel over—always remains horizontal; in other words, the compass is swung on gimbals. It is placed within the *binnacle.*

4. Variation or Declination.—The needle seldom or

never points due N. "The geographical meridian of a place is the imaginary plane passing through this place and the two terrestrial poles. Similarly, the magnetic meridian of a place is the vertical plane passing at this place through the two poles of a movable magnetic needle. The *angle* which the magnetic meridian makes with the geographical is called the variation of the magnetic needle," or variation is the angle which the magnetic needle makes with the geographical meridian.

5. Deviation.—The iron in the build of a ship, the attraction of iron-stone deposits on land, the cargo in a ship's hold, the tanks, the direction of the ship's head while building, etc., affect the compass. The error caused by these elements is termed *Deviation* or *Local Attraction;* sometimes a distinction is made between deviation and local attraction thus: whatever error of the compass arises from objects *within* the ship is termed *deviation,* whatever is caused by objects *exterior* to it, *local attraction.* Closely connected with the local attraction and deviation, we have what is known as *permanent* and *sub-permanent* magnetism. The direction of a ship's head during the time she is building, and the hammering to which she is subjected, frequently cause a ship to acquire a large amount of induced magnetism; and this once hammered in cannot by any change of position, or grating on rocks, or knocking about by waves, be entirely eradicated. That portion of this induced magnetism which no subsequent mechanical violence destroys, is called the permanent magnetism of the ship, while that portion which can be or is removed, by grating against piers, by seas, etc., is the *sub-permanent* magnetism. Thus we see that a new ship, after and on leaving port, is liable to have its magnetism considerably altered by the waves of the sea, etc.

6. Inclination or Dip.—A magnetic needle balanced on its centre of gravity does not remain horizontal, its north point in the northern hemisphere, and its

south point in the southern hemisphere, dipping considerably; this is what is meant by dip or inclination of the needle. The dip is subject to slight variations, and at the present time in England it is about 68°. At the magnetic equator, which does not coincide with the terrestrial equator, but is inclined at about an angle of 12° to it, the dip is *nil*, or the needle will lie horizontally. As we go from the equator towards the poles the dip increases regularly, so that at the magnetic poles the dipping needle is vertical. The magnetic poles lie, one in Boothia in 70° 14′ N. latitude and 96° 40′ W. longitude, the other to the south of Australia. But it should be noticed that there appears to be a pole in Siberia at 102° E. longitude and 60° N. latitude.

In London the variation of the compass is 20° 2′ W.; this means that the N. point of the needle is drawn 20° 2′ towards the W., so that the N.N.E. point of the compass points out very nearly the true N. point of the horizon. With such a compass, if we took the bearing of the Pole-star at night, by compass it would seem to be about N.N.E., *i.e.*, the N. point of the compass ought to be where the N.N.E. is; instead of that it is two points to the left of the N., therefore the compass has what is called two points westerly variation, for it is drawn out of its place two points towards the west by the induced magnetism of the earth.

In the Admiralty standard compass, four fixed parallel needles are employed as the active agent in the compass. It has been found that by using two needles parallel to each other, and intersecting the circumference of the card at the distance of 30° on either side of the N. and S. line, that the important source of error caused by semicircular and quadrantal deviation may be obviated. The deviation of the compass is enormously increased in vessels built of iron, especially in armour-plated vessels. The error is greatest when the ship's head is about due E. or W., and least when the keel lies on a line coinciding with the magnetic meridian. The errors of a compass

are always largely increased when the ship heels over by the action of the wind or waves. As well as the deviation depending on the materials of which a ship is built, it also depends upon the direction in which the ship's head lies while building. A bar of soft iron may be magnetized by induction from the earth by suspending it in the direction of the magnetic meridian; and, also, a large amount of magnetism may be hammered into an iron bar, which requires an equal amount of hammering to reverse. A ship is precisely in the same condition as the iron bar; if built with her head N. and S. she will receive a large amount of induced magnetism from the hammering to which she is subjected and from the earth. The harder the iron is, the less the change of position or hammering will affect it after being once magnetized. Hence the origin of *permanent* and *sub-permanent* magnetism as alluded to above. Some have come to the conclusion that the permanent and sub-permanent magnetism of a ship are the source of nearly every error in the compass. Deck beams, engine shafts, iron pillars, etc., in the vessel, are all disturbing causes, producing what has been termed—

(1) Vertical Induction, which is semicircular in its action.

(2) Horizontal Induction, which is quadrantal in its action.

7. **Semicircular Deviation** is caused by vertical induction. Vertical masses of iron on board ship, such as iron pillars to support the decks, become magnetized by induction from the earth; in our hemisphere, the upper end becomes a south pole and the lower end a north pole. As long as the vessel is on the magnetic meridian this does not affect the compass needle, but in any other position of the ship the needle will be drawn out of its position, and the greatest effect will be when the ship's head is E. or W. Hence, as a ship turns round through every point of the horizon this vertical induction disappears twice when the head is N. and S.,

and it is twice at a maximum when the ship's head is E. and W., therefore it has been called *semicircular deviation.*

8. **Quadrantal Deviation** is caused by the horizontal masses of iron in a ship, such as deck beams, engine shafts, etc., receiving induced magnetism from the earth. It is the effect due to horizontal induction. The effect of this is not manifested when the ship is in the direction of the magnetic meridian, nor when her head is due E. or W., but in positions lying between the cardinal points the disturbing influence is at a maximum. Hence, as in four positions the horizontal induction exerts a maximum influence, and at four a minimum influence upon the compass needle, it is named *quadrantal deviation.*

In certain places on the earth the compass has no variation. All such places are connected by imaginary curved lines, called the lines of no variation. These lines are not stationary. Such a line is sometimes termed an *agone;* there are two or three agones, the *American,* running through Rio Janeiro, Para, by Barbadoes and Guadaloupe to C. Hatteras, across the lakes of Erie and Huron to Hudson's Bay and the magnetic pole in Boothia; and the *Asiatic,* starting from Luzon in the Philippine Isles, passing near Amoy, through Lake Baikal, running N., crossing the Lena about 300 miles from its mouth, then coming down the Sea of Okhotsk, through the Kurile Isle back to Luzon. A third passes through Western Australia, turns S. at Java, curves by India, up the Arabian Sea, through Beloochistan, crosses the Caspian Sea, runs near Moscow, and through the White Sea and Lapland.

9. **The Effect of Compasses near each other.**—When two compasses are placed in the same binnacle one above the other, or when two binnacles are near each other, the compasses will mutually attract and repel each other, and the courses indicated by such compasses will be erroneous on all courses except due north, south, east, and west. On all other courses error will exist, and yet if the two

compasses are of the same power they will be found to agree. Place two compasses on a table near each other, and slowly turn the table round, this influence will then be readily seen. They will agree, as is intimated above, on the north, south, east, and west points; but on all other points they will give the bearing of a distant object different to what it is with either compass separated from the influence of the other.

10. Azimuth Compass.—We deem it right to give a short description of the azimuth compass, although it is an instrument employed chiefly in nautical astronomy. Azimuth compasses are employed to measure the angular distance of the sun or other celestial body from the south in north latitude, or from the north in south latitude; and also to measure its distance from the east when rising, or the west when setting. It is in reality an instrument for measuring horizontal angles, hence a prismatic compass is an azimuth compass. It resembles an ordinary compass as to its needle and the manner in which the needle is balanced; the card has two circles divided into degrees, one circle commencing its graduation from the north and south to measure azimuths proper, the other from the east to west to measure the amplitudes.

Affixed to the compass are two sight vanes—one the sight vane proper, having a fine thread stretched along its opening, by this thread the object observed must be bisected; the other has in it a slit through which the observer looks at the object. One is exactly opposite the other. The sight vanes are mounted with hinge joints so that they can be turned down flat out of the way when not in use. A mirror is attached to the instrument immediately behind the sight vane proper, in which the celestial object is reflected. Let us suppose we are going to take the bearing of the sun from the south in a morning or in the afternoon. The sight vanes are turned up so as to stand vertically, and the instrument is placed in a horizontal position; the observer then looks through the slit exactly opposite the thread stretched down the

sight vane proper, or else through a prism, and then turns the instrument round until the sun is observed reflected in the mirror, and the thread exactly bisects the sun; he then touches a spring to steady the card and reads off the division upon the card, which appears to coincide with the prolongation of the thread; this is the *magnetic* azimuth of the sun, or its bearing from the south. Nautical astronomy teaches us to calculate the *true* azimuth, when, by comparing the true and magnetic azimuth, we can determine the variation of the compass.

11. Swinging a Ship.—In every position of the earth the compass has a certain variation. Charts are constructed, called variation charts, with lines drawn through all places that have the same variation, so that by examining one of these charts the mariner knows at a glance the error of his compass for the position of his ship in every part of the world. It will be understood that the deviation affecting the needle, also the actual error of the compass, will differ from the variation chart so that if we know the whole error of the compass, which is readily ascertained by astronomical observations, the difference between that and the chart is the deviation. The whole error of the compass can be ascertained by several simple methods. The following is one of these :—At mid-day or apparent noon, the sun is exactly in the S. in north latitude and in the N. in south latitude, so that if a straight edge or long parallel ruler be laid across the centre of the compass, and pointed exactly at the sun, and then the angle that the needle makes with this ruler be noticed, we shall have the whole amount of error; if in the north latitude the needle point to the left of the sun, the error is easterly, if right of the sun the error is westerly; so, therefore, if we want to find the *true* north on the compass card, westerly variation must be allowed to the *right* and easterly to the *left; i.e.*, if we want the true north, and the compass points two points left of north, we must bring it back to the right two points, and *vice versa.* Knowing the total error of the

compass, it will be seen, then, that it is quite possible to separate variation from deviation; and it will now be easily believed and understood that the deviation is different, considering semicircular and quadrantal deviation, for every point of the compass. The actual error for each point of the compass is ascertained by several methods called swinging the ship. The simplest method, though not perhaps always the most accurate, is the following:—Two compasses are employed: the standard compass on board the ship, and one on shore. The ship is swung round to each of the 32 points of the compass; as it swings round to each point the bearing of the compass on shore is observed from the ship, and at the same instant (by preconcerted signals) the bearing of the ship's compass is observed from the land. The observations on shore are first reversed, to bring them into the same direction as those taken from the ship, and compared with the latter; the difference between the two is the error of the *ship's* compass. This is sometimes spoken of as the method of *reciprocal bearings*. Let us take a practical illustration. "The standard compass on board makes S.W.½W., and that on shore N.E. by E.½E, what is the deviation?" Inverting the latter we have to compare the two,

Observed.	*True.*
S.W.½W.,	S.W. by W.½W.,

and see what the amount of deviation is, and whether it be E. or W.

S.W.½W. (ship) is 4½ points right of south; S.W. by W.½W. (shore) is 5½ points right of south. The difference shows *one* point *deviation*, and as the shore or true observation is to the right of the ship's, the deviation is *easterly*. Had the shore or true observation been to the left of the ship's, the deviation would have been westerly. Every point is treated in precisely the same way, and a table of points is written out, and the amount of deviation tabulated opposite every point, as seen in the table annexed.

DEVIATION TABLE.

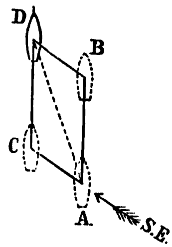
N. 2° 20′ E.	E. 6° 40′ E.	S. 2° 45′ W.	W. 8° 0′ W.
N.byE. 3° 40′	E.byS. 5° 40′	S.byW. 3° 50′	W.byN. 7° 40′
N.N.E. 5° 40′	E.S.E. 4° 40′	S.S.W. 5° 20′	W.N.W. 6° 40′
N.E.byN.6°50′	S.E.byE.3°40′	S.W.byS. 6° 0′	N.W.byW.5°40′
N.E. 8° 0′	S.E. 2° 0′	S.W. 6° 30′	N.W. 4° 30′
N.E.byE.8° 10′	S.E.byS. 1° 0′	S.W.byW.7°30′	N.W.byN.3°10′
E.N.E. 7° 20′	S.S.E.0°30′W.	W.S.W. 7° 40′	N.N.W. 1° 50′
E. by N. 7° 35′	S.byE. 1° 30′	W.byS. 8° 10′	N.byW.0°40′E.

The first column shows the direction of the ship's head, the second the deviation.

To find the deviation from two reciprocal bearings, first ascertain their difference, then draw two lines at right angles to each other, and let the ends represent the four points of the compass; then draw lines to the points of the compass to represent the two bearings, and imagine yourself to be placed in the centre of the compass; then if the shore observation is to the right of that taken from the ship the deviation is easterly, while if it be to the left, it is westerly.

12. Leeway.—When a ship's head is pointed in any particular direction, on account of the action of the wind upon the side of the ship and upon the sails, it does not move *exactly* in that direction, but is driven a little out of its course. The amount that the ship is drawn from its compass course is called **Leeway.** A more exact definition would be this:—Leeway is the angle between the course and the direction in which the ship is actually moving; or, leeway is the angle which the rhumb line on which the ship really sails makes with the rhumb line on which she endeavours to sail. When the vessel is close hauled the pressure of the wind and the surge of the sea cause her to fall off sideways to *leeward;* hence it is called leeway. The amount of leeway depends upon the lines and trim of the ship, the depth of water drawn, the sails used, whether the ship be as near the wind as she

will lie, etc. It is evident that if the wind be right behind the ship she will make but little leeway, and as the wind moves more to the side of the vessel the leeway must increase. The old fashioned custom was to allow leeway in proportion to the sails used. In correcting a course, leeway is always allowed *from* the wind. Notice particularly in which direc tion the wind would drive the ship, and allow the leeway accordingly. Imagine the ship to be at A, sailing in the direction A B, and the wind comes from S.E.; let us suppose that in one hour the ship would go from A to B if not influenced by leeway, whilst if left alone to the influence of the wind it would be driven from A to C in an hour. By the first principles of mechanics it will be found neither at C nor B at the end of the hour, when both influences are acting together, but at D, the vessel having been driven along A D, the diagonal of the completed parallelogram. Hence, as was said before, leeway must be allowed from the wind. If the wind is on the right hand side of the ship, or starboard, the leeway must be called *left*; while if it be on the port or left hand side it must be reckoned as right.



When the wind is exactly behind the ship it is said to be *abaft;* hence the expression, "the wind being abaft." When the wind is perpendicular to the side of the ship it is said to be on the beam; when between these two positions it is said to be so many degrees abaft the beam.

We will now give a few definitions, and then return to the subject of the compass again.

The shape of the earth is that of a sphere or globe slightly flattened at the top and bottom.

Latitude is the distance of a place N. or S. from the equator.

Axis of the earth.—The axis of the earth is the ima-

ginary line upon which the earth is supposed to turn once in twenty-four hours.

Poles.—The ends of the axis are called the N. and S. poles.

Equator is an imaginary line, in fact a great circle, drawn round the earth at equal distance from the two poles.

Equinoctial is the great circle of the sky corresponding to the extension of the equator of the earth.

The teacher must carefully point out the error sailors make in calling the equator, as they frequently do, the *equinoctial*, or equinoctial line.

Diameter of the earth is a line drawn through the centre of the earth to each side of a great circle. We have the equatorial diameter and the polar, the latter being 26 miles shorter than the former.

Through all places, at the same distance from the equator, lines are drawn round the earth, these are termed *parallels of latitude.*

The **Latitude from** is the latitude of the place *from* which the ship sails.

The **Latitude in** is the latitude of the place at which the ship has arrived.

Difference of Latitude is the difference between the "latitude from" and "latitude in."

Middle Latitude is the latitude of the place midway between the "latitude from" and "latitude in."

Meridional difference of Latitude.—See the chapter on Mercator's sailing.

Longitude is the distance of a place E. or W. of Greenwich. A great circle passing through Greenwich and the N. and S. poles of the earth, dividing the earth into two hemispheres, passes through all places that have the same longitude as Greenwich. This is called the meridian of Greenwich, and for all astronomical calculations made in England, charts, maps, etc., it is the first meridian. All other great circles passing through the poles of the earth are termed *meridians.*

Longitude from is the longitude of the place from which the ship sailed.

Longitude in is the longitude of the place at which the ship has arrived.

Difference of Longitude is the difference between the "longitude from" and "longitude in."

The use of latitude and longitude is to determine the precise position of a place on the earth's surface. The equator and first meridian are two imaginary fixed lines in position. It is well understood that if we know the situation of a point in regard to two fixed lines, its exact position is determined. Let the student take a piece of paper and draw on it two lines at right angles to each other, and then fix upon determinate distances from each line, above, below, right or left, and he will immediately perceive the truth of the above statement.

Starboard is the right hand side of the ship, looking towards the direction in which she is moving.

Port (or larboard) is the left hand side of the ship, looking in the same direction.

Starboard Tack.—A ship is said to be on her starboard tack when sailing with the wind blowing on the right hand side of the ship, and on her **Port Tack** when sailing with the wind on the left hand side of the ship.

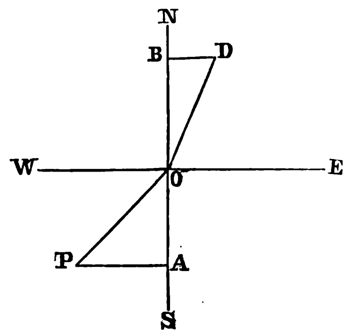
Course is the angle which a ship's track makes with the meridian.

Distance is the distance in nautical miles that a ship runs in any direction.

Departure is the perpendicular distance between the meridian left and the meridian arrived at. This, with difference of latitude, was defined on the preceding page. Let a ship be supposed to sail from O to P: then O P is the distance, A O is the difference of latitude, A P is the departure, and A O P is the course.

Remember distinctly that **P O W** is NOT the course, but **A O P.**

Again, to illustrate these points once more, let a ship be supposed to sail from O to D: then O D is the distance,



O B is the difference of latitude, D B is the departure, and D O B is the compass courses.

CORRECTION OF COURSES.

We now come to one of the most important parts of our subject—the correction of compass courses.

Rules:

Put down your course, calling it so many points or degrees, right or left of N. or S.
Allow easterly variation to the right, westerly to the left.
Allow the leeway from the wind.
Treat deviation precisely the same as variation.

A. A vessel steers by her compass E.S.E., the variation and deviation amount to $2\frac{3}{4}$ points E., the wind

is N. E, causing $\frac{3}{4}$ of a point leeway, find the true course.

Compass Course E.S.E. is 6 points, or	67° 30′ 0″ l. of S.
Variation and Deviation, $2\frac{3}{4}$ points, or	30° 56′ 45″ r.
	36° 33′ 15″ l.
Leeway, $\frac{3}{4}$ point, or	8° 26′ 15″ r.
True Course,..........	28° 7′ 0″ l.
	or S. 28° 7′ 0″ E.

B. The compass course is S.W. by W., the variation $1\frac{3}{4}$ points E., deviation 14° E., and the wind in the N.N.W., causing $1\frac{1}{4}$ points leeway, find the true course.

Compass Course S.W. by W. is 5 pts, or	56° 15′ 0″ r. of S.
Variation is $1\frac{3}{4}$,,	19° 41′ 15″ r.
	75° 56′ 15″ r.
Deviation, ...	14° 0′ 0″ r.
	89° 56′ 15″ r.
Leeway, $1\frac{1}{4}$ pts., or	14° 3′ 45″ l.
True Course,............	75° 52′ 30″ r. of S.
	or S. 75° 52′ 30″ W.

C. A ship sails N.N.E., the variation is $2\frac{1}{4}$ points W., the deviation 16° 8′ E., and wind is N.W., required the true course when the leeway is 2 points.

Compass Course N.N.E. is 2 pts., or	22° 30′ 0″ r. of N.
Variation is $2\frac{1}{4}$ pts., or	25° 18′ 45″ l.
	2° 48′ 45″ l.
Deviation,................	16° 8′ 0″ r.
	13° 19′ 15″ r.
Leeway, 2 pts.,.........	22° 30′ 0″ r.
True Course,.............	35° 49′ 15″ r. of N.
	or N. 35° 49′ 15″ E.

D. The compass course is W. by N., the variation 2 points E., the deviation 21° W., while the leeway is 2 points, and the direction of the wind N. by W., find the true course.

W. by N. is 7 pts., or	78° 45′ 0″ l.	of N.
Variation is 2 pts.,....	22° 30′ 0″ r.	
	56° 15′ 0″ l.	
Deviation,...............	21° 0′ 0″ l.	
	77° 15′ 0″ l.	
Leeway, 2 pts.,........	22° 30′ 0″ l.	
	99° 45′ 0″ l.	of N.
	180° 0′ 0″	
True Course,...........	80° 15′ 0″ r.	of S.
or S.	80° 15′ 0″ W.	

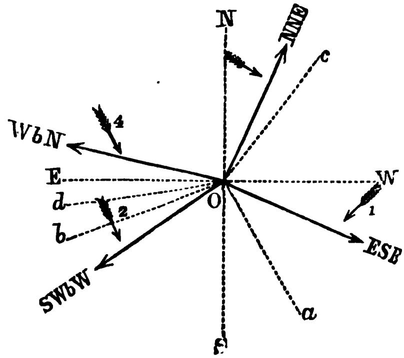
E. A ship is steering by compass N.W. ¾-W., the variation of the compass is 2¼ points W., the wind is S.E., leeway ¼ point, deviation 5°⅔ E., find the true course.

N.W. ¾-W. is 4¾ pts., or	53° 26′ 15″ l.	of N.
Variation is 2¼ pts., or...	28° 18′ 45″ l.	
	81° 45′ 0″ l.	
Deviation,....................	5° 40′ 0″ r.	
	76° 5′ 0″ l.	
Leeway, ¼ pt.,...............	2° 48′ 45″ r.	
True Course, ...	73° 16′ 15″ l.	of N.
or N.	73° 16′ 15″ W.	

Remarks on the above five courses, and the method by which they are done :—

In example A, the vessel steers E.S.E., which is six points left of S. (suppose you stand at O and face the S.), the variation and deviation amount to 2¾ points

east, which means that the N. end of the needle has been drawn towards the E., and, therefore, to get the true



course we must go nearer the S., or really nearer the W., or we subtract them. Again, as the wind comes from the N.E. in the direction of the arrow (1), it will evidently drive the ship more towards the S., or we must subtract the leeway to make the angle smaller, which gives us the true course in about the direction of dotted line *a*.

In example B, the vessel steers S.W. by W. by compass, or 5 points to the *right* of S., the variation is $1\frac{3}{4}$ points E., which means that the compass has been drawn towards the E., so we must add on the right hand to get back again nearer the W.; the deviation precisely the same. The wind being on the starboard side of the ship, as shown coming from the N.N.W. in the direction indicated by arrow (2), we must subtract the leeway as ship is driven *nearer the south.* This shows that the ship, although sailing S.W. by W. by compass, has been really going S. 75° $52\frac{1}{2}'$ W., in the direction shown by line *b*.

In example C, the vessel is steered N.N.E. by the compass, or *two* points *right* of N., the variation being

$2\frac{1}{4}$ points W., the compass is drawn that much towards the W., so, therefore, in applying it to a course to the right of N., we add it to bring it nearer the N., while the deviation, being easterly, is for an opposite reason subtracted. The wind coming from the N.W., and being on the port side of the ship, drives it to the right, so we make the angle greater on the right of north, which gives us the true course N. 35° 49′ E., marked *c* in the figure.

Example D will call for no further remark but this:— It will be seen that after variation, deviation, and leeway are applied that the course is greater than 90°, or we have gone through the W. from the N., and have come nearer S. than *N.*, so, therefore, we subtract from 180°, which gives us the true course as S. 80° 15′ W. *from the South.*

Example E. Here we must call attention to the fact that in applying the leeway the student must look to the direction of the ship's head and the wind, as indicated by the compass, or else he may sometimes get confused when the wind is nearly abaft the ship, to know whether he ought to add or subtract; if he consider only the position of the ship when the deviation and leeway have been applied, he may fall into error.

GIVEN THE FOLLOWING COMPASS COURSES TO FIND THE TRUE COURSES.

	Compass Course.	Variation.	Deviation.	Wind.	Leeway.	True Course.
1.	N.	23° W.	4° 15′ E.	S. by E.	Nil.	N. 18° 45′ W.
2.	W. N. W.	2 points E.	8° W.	S.	2 points.	N. 30° 30′ W.
3.	N. E. by E.	1¾ points E.	18° E.	S. by E.	2 points.	N. 71° 26′ 15″ E.
4.	S. S. E.	27° 30′ E.	5° W.	W. by N.	1½ points.	S. 16° 52′ 30″ E.
5.	S.	11° 15′ W.	6° W.	N. N. E.	¾ point.	S. 8° 48′ 45″ E.
6.	W. by N.	18° E.	6° 45′ W.	S. S. E.	1 point.	N. 56° 15′ 0″ W.
7.	E. N. E.	3 points W.	18° 30′ E.	S. by W.	½ point.	N. 46° 37′ 30″ E.
8.	S. E. ¾-E.	22° 30′ W.	4° 15′ E.	W.	1¼ points.	S. 85° 45′ 0″ E.
9.	E.	18° 45′ E.	16° 53′ E.	N. W.	2 points.	S. 31° 52′ 0″ E.
10.	N. W. by W.	25° W.	5° 15′ W.	E. N. E.	1¾ points.	S. 73° 48′ 45″ W.
11.	E. by S. ½-S.	2½ points E.	13° 20′ E.	W.	½ point.	S. 37° 17′ 30″ E.
12.	W.	1¼ points W.	8° W.	N.	2½ points.	S. 39° 48′ 45″ W.

13. Suppose a ship to sail by compass S.S.W., the variation being 1 point easterly, required the true course. *Ans.* S. W. by S.

14. Being at sea, coming up the English channel the pole star bore N. 28° W., what was the deviation and variation combined? *Ans.* 28° E.

15. Suppose in the last question the variation is 22° 30′ E., what is the deviation? *Ans.* 5° 30′ E.

16. Being at sea, the Eddystone light bore N.E. by E. $\frac{1}{4}$-E. by compass, the variation being $1\frac{1}{2}$ points westerly, required its true bearing. *Ans.* N.E. $\frac{1}{4}$-N.

17. A ship sails E. by S. by her compass, the variation is 2 points W., the wind S., and the leeway $1\frac{3}{4}$ points, find the true course. *Ans.* N.E. by E. $\frac{1}{4}$-E.

18. Find the true course when a ship sails due S. by compass; the wind is N. W., giving $\frac{3}{4}$-point leeway; variation 1 point E., and deviation $\frac{1}{4}$-point W. *Ans.* S.

TO FIND THE COMPASS COURSE.

13. When a ship is leaving port, the master examines his chart, and shapes his course accordingly; but since the compass is seldom or never correct, he has to consider his variation and deviation to find on what course he must sail by his compass. To find his compass course he reverses the whole of the operations explained in the last few pages. He *allows easterly variation to the left, westerly to the right,* and guessing pretty nearly what the leeway will be, allows it *towards the wind.*

For instance, suppose a man wishes to sail S.W. from the Lizard, when he knows his variation is 20° 8′ W. and deviation 11° 15′ E., the wind being N., he allows $\frac{3}{4}$ of a point leeway, let us see what course he must sail by his compass:—

True course, 4 pts. or	45° 0′ 0″ r. of S.
Variation, ...	20° 8′ 0″ r.
	65° 8′ 0″ r. of S.
Deviation, ...	11° 15′ 0″ l.
	53° 53′ 0″ r. of S.
Leeway, ...	8° 26′ 15″
Compass course, ...	62° 19′ 15″ r. of S.
	or S. 62° 19′ 15″ W.

Example 19. A master wishes to make an island bearing true N. 40° W., his compass has 25° 14′ E., variation and deviation 9° 30′ W., the wind is in the E., and he allows a point and a half leeway, on what *compass* course must he sail?

True course,.........	40° 0′ 0″ l. of N.
Variation,...........	25° 14′ 0″ l. of N.
	65° 14′ 0″ l.
Deviation,...........	9° 30′ 0″ r.
	55° 44′ 0″ l.
Leeway,...............	16° 52′ 30″
Compass course,....	38° 51′ 30″ l. of N.
	or N. 38° 51′ 30″ W.

We will endeavour to explain the method by which the above sum is worked, but again repeat that it is nothing but reversing every process in finding the true course from the compass course.

(1) The ship sailing to the left of N. and the variation being E., it is added to the course, because the N. end of the needle being pulled round to the E., the compass card is pulled with it in that direction. Therefore, to get the rhumb on which we must sail by the compass, we must add it to the true course to make the angle larger, the variation has decreased it; the deviation being E., the opposite reason applies, so it is subtracted. The leeway is also subtracted in this case to find the compass course, because it makes the true course really greater than the compass course. So we might also have reasoned with the variation, and have said it is added to obtain the compass course, because it makes the true ccurse less than it really is.

UNDER THE FOLLOWING CONDITIONS FIND THE COMPASS COURSES:

	True Course.	Variation.	Deviation.	Wind.	Leeway.	Compass Course.
1.	E.	2 points W.	5° W.	W.	Nil.	S. 62° 30′ 0″ E.
2.	S. by W.	1½ points E.	9° 30′ W.	E.	1 point.	S. 7° 22′ 30″ E.
3.	N.W. by W.	20° E.	2° W.	E.	1½ points.	N. 57° 22′ 30″ W.
4.	N.E.	1¾ points W.	13° E.	S.W.	Nil.	N. 51° 41′ 15″ E.
5.	E.S.E.	Nil.	13° E.	N.	1¼ points.	N. 85 ° 26′ 15″ E.
6.	W. by S.	11° 15′ E.	9° W.	N.N.E.	2 points.	N. 81° W.

7. How are courses corrected for variation and deviation? Give the rule for applying the variation and deviation to a true course to obtain the magnetic course (1868).

8. Having found by Mercator's sailing that my course must be true S. 70° E., find the compass course, with variation 34° W., deviation 8° E., and leeway (supposed) ¼ pt., wind W.N.W.

Ans. S. 41° 11′ 15″ E.

9. I have found by middle latitude sailing that my course must be true N., find the magnetic course when the wind is E., variation 25° E., and deviation 4° W., and leeway 2 pts.

Ans. N. 1° 30′ E.

10. Find the compass course from Southampton to Jersey, when by the chart the bearing of Jersey from Southampton is S. 30° W., the wind N., and the variation 20° 8′ W., and deviation 9° W., leeway 1 point.

Ans. S. 70° 23′ W.

EXAMINATION QUESTIONS ON VARIATION, DEVIATION, AND DIP.

1. Explain what is meant by the variation and deviation of the compass (1863).

2. Define the terms "Deviation," "Variation," and "Local Attraction." On what does the first of these depend? and state briefly the laws which it follows (1864).

3. What is the difference between variation and deviation? How is the latter correction found (1864)?

4. To what causes are the deviation of the compass in an iron ship chiefly due (1865)?

5. What is meant by sub-permanent magnetism? To what change is it liable when the ship is at sea? Why is attention to ship's compasses especially necessary during the first days of its being at sea? In what direction is it most desirable to place an iron ship while building in northern latitudes (1865)?

6. Explain accurately the several causes which affect the correctness of the compass. Show how they are compensated or allowed for (1866).

7. State accurately the several causes which affect the compasses of a ship arising from what is called local attraction (1866).

8. Why is it necessary to ascertain the effects on a compass of local attraction? What name is given to the whole effect, and how is it taken into consideration in estimating the ship's course?

9. Not having a table of deviations, I find that, in order to enable a ship to sail on a course which I know to be true magnetic S. $\frac{3}{4}$-W., I am obliged to steer her by standard compass S. by W. $\frac{1}{4}$-S.: what is the deviation for this direction of the ship's head (1867)? *Ans.* Nil.

10. Describe the mariner's compass. How is it divided? A ship starting on an E.N.E. course goes round gradually through the N. until she is on a S. by W. course, through how many points has she turned? State also the number of degrees (1869). *Ans.* 21 points, or 236° 15′.

11. Explain, as to a class, the mode of correcting a course for variation, with examples (1866).

12. What is meant by variation of the compass? To what cause is it due (1866)?

13. Explain the method of swinging a ship for the purpose of making tables of deviation. The standard compass on board marks S.W. $\frac{1}{2}$-W., and that on shore N.E. by E. $\frac{1}{2}$-E., what is the deviation (1872)? *Ans.* Deviation is 1 point E.

14. What is meant by the variation of the compass? Describe the course of the lines of no variation. Explain the terms "Dip of the Needle," "Local Deviation," and give the law which governs the dip (1861).

15. Explain the method of ascertaining the deviation of the compass, and give some account of the methods employed for correcting it (1861).

16. Explain accurately what is meant by deviation, variation, and local attraction, and show briefly the effects of inductive magnetism on the compasses of iron ships (1863).

17. What is meant by the corrections of variation, deviation, and leeway? and show accurately how they must be applied to obtain the true course from the compass course. Illustrate by a figure (1865).

18. What law does the attraction of one compass on another follow as the angle, at which it is inclined to it, changes. How does this affect the deviation (1867)?

19. Describe the means by which tables of deviation are obtained (1868).

20. Define variation and deviation. Suppose a shore compass bears from a ship's compass N. 63° E., but the ship's compass bears from the shore compass S. 42° W., what do you conclude from this? What is this method called (1870)?

Ans. The deviation is 15° W.

21. What corrections must be applied to the compass course to obtain the true course, and with what algebraical sign must they be applied? State as fully as you can on what corrections depend (1871).

EXAMINATION QUESTIONS ON THE COMPASS, LEEWAY, COURSES, Etc.

1. A ship is steering by compass N.W. ¾-W., the variation of the compass is 2¼ points W., the wind is S.E., leeway ¼ point, deviation 5°⅜ W.: find the true course.

Ans. N. 81° 36′ 15″ W.

2. Given the true course N. 30° E., the variation of the compass 2½ points W., and deviation on account of local attraction 6° 15′ E. Construct a figure and find the corrected compass course (March 1864)? *Ans.* N. 51° 52′ 30″ E.

3. Show, by a figure, how in correcting a course variation should be allowed. The true course is N.W. ¾-W., variation 1½ points E., what is the compass course (1865)?

Ans. N. 70° 8′ 45″ W.

4. What is meant by rhumb line. Draw a diagram illustrating your definition, and mark on it the course (1867).

5. How is the course corrected for leeway? A ship is sailing on the apparent course, N.E. ½-E., wind N., leeway 2½ points, what is the correct course (1867)? *Ans.* E. by N.

6. What is the rule for obtaining the magnetic course from the true course? The course is N. ¾-W., variation of the compass 2 points W., what is the magnetic course (1867)?

Ans. N.byE.¼-E.

7. Describe the azimuth compass. How are the bearings of two objects observed by it (1868)?

8. A ship is sailing on the apparent course N.W.¾-W., what is the true course, given variation 1½ points E., deviation 8° 10′ W., leeway 1¼ points, the direction of the wind N.byE. (1868)?

Ans. N. 58° 47′ 30″ W.

9. Draw the quarter of the compass between S. and E.; write down the names of the points and also their value in degrees, etc., going from S. to E. How many degrees are there between N.N.W.½-W. and E.byN.¼-N. (1870)?

Ans. 9¼ points, or 104° 3′ 45″.

10. How is the direction in which a ship is steered measured? By what name is it known (1870)?

11. How must I steer by compass when my true course is S.W.byW.¾-W., variation 2½ points E., deviation ¾ points W., leeway ¼ point, wind S.byE. (1870)?

Ans. S. 42° 11′ 15″ W.

12. Describe the instrument used for determining the course at sea. A ship is sailing in the direction N.E.¾-E., find the number of points and of degrees, etc., between her course and the meridian, reckoning from the S. point (1871).

Ans. 11¼ points or 126° 33′ 45″.

13. Correct the courses in the following (1871):—

Compass Course.	Variation.	Deviation.	Leeway.	Wind.	True Course.
W. by N.	2 pts. E.	11° W.	2 pts.	N. by W.	N.89°45′ 0″W.
W.S.W.	1¼ pts. W.	6° 30′ W.	1½ pts.	E. by S.	S. 63°48′45″W.
N.	1½ pts. W.	2° 40′ E.	1 pt.	E. by S.	N.25°27′30″W.

14. A ship is known to be sailing due S., but the compass course steered is S.byW.¾-W., the variation of the compass is 1½ points W., what is the deviation (1871)?

Ans. ¼ point W.

15. Define rhumb-line. What is the name given to the angle which a rhumb-line makes with a meridian?

16. A ship is sailing N.E.¾-E., and the direction of the head is changed by 118° through the N., what is the new course of the ship in points to the nearest quarter (1872)?

Ans. N.W.byW.¾-W.

17. What are the several corrections to be applied to the apparent to obtain the true course? Correct the following courses (1872) :—

APPARENT COURSE.	VARIATION.	DEVIATION.	LEEWAY.	WIND.	TRUE COURSE.
N.W.	$1\frac{3}{4}$ pts. E.	10° W.	$2\frac{1}{2}$ pts.	N.N.E.	N.63°26′15″W.
S. W$\frac{1}{2}$-W.	2 pts. W.	4°$\frac{1}{4}$ W.	$1\frac{3}{4}$ pts.	S.S.E.	S. 43°33′45″W.
N.	$1\frac{1}{4}$ pts. E.	11° E.	Nil.	S. by E.	N.25° 3′45″E.
S. by E.	$1\frac{1}{2}$ pts. E.	3° E.	$1\frac{3}{4}$ pts.	W.S.W.	S. 11° 3′45″W.

18. Explain the mode of correcting courses: (1) for leeway; (2) for variation; (3) for deviation. The compass course of a ship is S.byW.$\frac{1}{4}$-W., variation $2\frac{1}{4}$ E., wind S.E.$\frac{1}{4}$-E., leeway $2\frac{1}{4}$, deviation 5° W. Find the true course (1863).

Ans. S. 59° 41′ 15″ W.

19. Show how to correct a course for leeway (1864).

THE DIFFERENCES OF LATITUDE AND LONGITUDE.

1. The latitude of A is 45° 15′ 51″ N.; of B, 20° 10′ 14″ N Find the difference of latitude.

Latitude of A is 45° 15′ 51″ N.
,, B is 20° 10′ 14″ N.

Difference of latitude is 25° 5′ 37″ A north of B.

2. The latitude of a place A is 20° 14′ 11″ N.; of another, B, it is 19° 14′ 16″ S. Find how far apart these two parallels are:—

Latitude of A is 20° 14′ 11″ N.
,, B is 19° 14′ 16″ S.

Difference of latitude is 39° 28′ 27″ B is south of A.

These are the only two cases that can occur in finding the difference of latitude. *When the two places have the same name, both north or both south, subtract to find the difference of latitude; but when one is north and the other south, add to find their difference of latitude.*

The teacher must illustrate these points by drawing three lines on the board, one for the equator and two

for the parallels of latitude, when it is seen in a moment whether to add or subtract to find the difference of latitude or the distance apart of the two places.

There are three different cases in finding the difference of longitude: (1) when both are east or west; (2) when one is east or west; (3) when the sum in the second case is greater than 180°.

3. Find the difference of longitude between A in longitude 45° 17′ 18″ E. and B in longitude 74° 20′ 48″ E.

Longitude of A is 45° 17′ 18″ E.
,, B is 74° 20′ 48″ E.

Difference of longitude is 29° 3′ 30″. A being west of B.

4. Find the difference of longitude between two places, one on the meridian 27° 18′ 45″ E. of Greenwich, the other on that 110° 14′ 15″ W. of Greenwich.

Longitude of A is 27° 18′ 45″ E.
,, B is 110° 14′ 15″ W

Difference of longitude is 137° 33′ 0″. A being east of B.

5. Find the difference of longitude between A in longitude 121° 17′ 24″ E. and B in longitude 95° 16′ 18″ W.

Longitude of A is 121° 17′ 24″ E.
,, B is 95° 16′ 18″ W.

216° 33′ 42″
360° 0′ 0″

Difference of longitude is 143° 26′ 18″. A being west of B.

By a careful perusal of these three cases it is seen that, to find the difference of longitude, we must use the following rules:—

When the two longitudes have the same name we must subtract; when they have different names, we must add; if, after we have added, the sum is greater than 180°, we subtract it from 360°, and this gives the difference of longitude.

The teacher should accustom the pupils to demonstrate these facts by illustrations, simply drawing a horizontal line on the paper or slate to represent the equator, and a vertical line crossing it at right angles for the first meridian;

he will then see that if the two longitudes represented by two other straight lines are both on the right or both on the left side of the first meridian, *i.e.*, both west or both east, he has to subtract to find their distance apart, while if they be one on each side of the first meridian, *i.e.*, one east and the other west, he must add to find the difference of longitude. The case in which the sum is greater than 180° is best illustrated by a circle, on which it must be shown that the distance apart of two places is the smaller arc of the circle, not the larger one.

In middle latitude sailing, the mid-latitude, or the parallel half way between any two given parallels, will have to be found; it will be better to show now how this is done by a few simple illustrations:—

6. Find the mid-latitude between Cape Cornwall, latitude 50° 8′ 0″ N. and Duncansby Head in latitude 58° 39′ 45″ N.

Latitude of Cape Cornwall,	50° 8′ 0″ N.
,, ,, Duncansby Head,	58° 39′ 45″ N.
2)	108° 47′ 45″
Mid-lat. between the two is	54° 23′ 52½″ N.

We might have taken one from the other, then half of the difference, and added it to the lower or least latitude, that would have given us the exact middle point between the two, and would have been the simplest way of reasoning; but it admits of an easy algebraical proof, that if b be greater than a—

$$\frac{a+b}{2} \text{ is the same } a + \frac{b-a}{2}$$

$\frac{a+b}{2}$ being the method we have employed.

$a + \frac{b-a}{2}$ the method referred to in the text above.

7. Find the middle latitude between Cape Lopez 0° 36′ 10″ S. and the Cape of Good Hope 34° 22′ 0″ S.

Lat. of Cape Lopez, -	0° 36′ 10″ S.
,, ,, of Good Hope,	34° 22′ 0″ S.
2)	34° 58′ 10″
Mid-lat. is -	17° 29′ 5″ S.

8. Find the mid-latitude between the Gibraltar in latitude 36° 6′ 20″ N. and the Cape of Good Hope.

Latitude of Gibraltar,	-	36° 6′ 20″ N.
,, ,, Cape of Good Hope,		34° 22′ 0″ S.
	2)	1° 44′ 20
Mid-lat. is	-	0° 52′ 10″ N.

9. Find the mid-latitude between Gibraltar and Cape Cornwall. *Ans.* 43° 7′ 10″ N.

10. Find the mid-latitude between Cape Lopez and Duncansby Head. *Ans.* 29° 1′ 47½″ N.

11. Find the mid-latitude between Singapore, latitude 1° 16′ N., and Kandy in Ceylon, latitude 7° 20′ N. *Ans.* 4° 18′ N.

12. In the latter case find the difference of latitude. *Ans.* 6° 4′.

13. Find the mid-latitude between Pekin, latitude 39° 54′ N., and Rio Janeiro, latitude 22° 54′ S. *Ans.* 8° 30′ N.

14. Find the mid-latitude between Plymouth and Manchester, when Plymouth is in latitude 50° 23′ N., Manchester 53° 29 N. *Ans.* 51° 56′ N.

15 Find the mid-latitude between Lisbon, which is situated in latitude 38° 12′ N., and Bergen in Norway, latitude 60° 24′ N. *Ans.* 49° 18′ N.

16. In the last question find the difference of latitude. *Ans.* 22° 12′.

In finding longitude presently, it will be frequently necessary to find the *co-mid-latitude*, that is, *the distance of the middle latitude between two given places from the nearest pole.*

17. Required the co-mid-latitude between Cape Cornwall and Duncansby Head.

Latitude of Cape Cornwall is	-	50° 8′ 0″ N.
,, Duncansby Head,	-	58° 39′ 45″ N.
	2)	108° 47′ 45″
Mid-lat. - -	-	54° 23′ 52½″
		90° 0′ 0″
Co-mid-lat. is -	-	35° 36′ 7½″

Having found the mid-latitude as in previous questions, it is evident that the distance of this parallel from the pole is found by subtracting it from 90°, for as from the equator to the poles there are 90°, and as the mid-latitude brings us a certain distance from the equator, the distance of this place from the pole is its defect from 90°.

18. Find the co-mid-latitude of Cape Lopez and the Cape of Good Hope.

Cape Lopez	is in lat.	0° 36′ 10″ S.
Cape of Good Hope	„	34° 22′ 0″ S.
		2) 34° 58′ 10″
Mid-lat.	-	17° 29′ 5″
		90° 0′ 0″
Co-mid-lat. is	-	72° 30′ 55″

19. Find the co-mid-latitude of Gibraltar and the Cape of Good Hope.

Gibraltar is in lat.		36° 6′ 20″ N.
Cape of Good Hope,		34° 22′ 0″ S.
	2)	1° 44′ 20″
Mid-lat. is -	-	0° 52′ 10″ N.
		90° 0′ 0″
Co-mid-lat.	-	89° 7′ 50″

20. Find the co-mid-latitude between Pekin, latitude 39° 54′ N., and Rio Janeiro, latitude 22° 54′ S. *Ans.* 81° 30′.

21. Find the co-mid-latitude between Plymouth and Manchester, when Plymouth is in latitude 50° 23′ N., Manchester 53° 29′ N. *Ans.* 38° 4′.

22. Find the co-mid-latitude between Lisbon and Bergen in Norway, when Lisbon is situated in latitude 38° 12′ N., and Bergen in latitude 60° 24′ N. *Ans.* 40° 42′.

23. Required the difference of latitude and the difference of longitude between the two places, A and B, given (1863).

Latitude.	Longitude.
A 31° 15′ 25″ N.	17° 30′ 27″ E.
B 45° 18′ 17″ N.	23° 14′ 3″ W.

Ans. Difference of latitude 14° 2′ 52″ B north of A.
Difference of longitude 40° 44′ 30″ B west of A.

24. Give definitions of the earth's axis, poles, meridians, and equator. How is the situation of a place on the earth's surface determined? What are the difference of latitude and the difference of longitude between A and B (1869)?

Latitude of A 13° 18′ N.	Longitude 123° 12′ E.
Latitude of B 33° 17′ S.	Longitude 74° 36′ E.

Ans. Difference of latitude 46° 35′ B south of A.
Difference of longitude 48° 36′ B west of A.

25. Canton is in latitude 23° 7′ 10″ N., longitude 113° 14′ 0″ E.; Cape Mendocino is in latitude 40° 29′ 0″ N., longitude 124° 29′ 0″ W.; find the difference of latitude and longitude between the

two places, and the position of Canton in reference to Cape Mendocino.

Ans. Difference of lat. 17° 21′ 50″ Canton south of Mendocino.
Difference of long. 122° 17′ 0″ Canton west of Mendocino.

26. Find the difference of latitude and longitude between Valdivia and Otago, and the relative position of Valdivia to Otago. Given

Lat. of Valdivia 39° 50′ 7″ S. Long. 73° 34′ 35″ W.
,, Otago 45° 46′ 28″ S. ,, 170° 36′ 45″ E.

Ans. Difference of lat. 5° 56′ 21″ Valdivia north of Otago.
Difference of long. 115° 48′ 40″ ,, east of Otago.

27. What is the difference of latitude and longitude between the Cape of Good Hope and Cape Horn. Given

Cape Horn, lat. 55° 58′ 40″ S. Long. 67° 12′ 25″ W.
Cape of Good Hope, lat. 34° 22′ 0″ S. Long. 18° 24′ 24″ E.

Ans. Difference of lat. 21° 36′ 40″ Cape Horn south.
Difference of long. 85° 36′ 49″ Cape Horn west.

28. Sombrero Rock is in latitude 10° 45′ 0″ N., longitude 121° 38′ 0″ E.; the north point of Owhyhee is in latitude 20° 18′ 30″ N., long. 155° 58′ 0″ W. Find their distance apart in degrees, etc., of latitude and longitude.

Ans. Difference of latitude 9° 33′ 30″.
Difference of longitude 82° 24′ 0″.

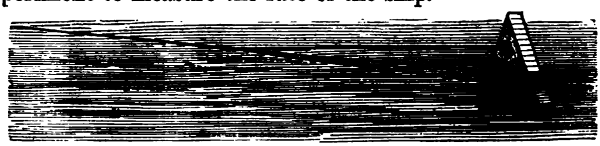
LOG, LOG GLASS, AND LOG LINE.

We have spoken of the compass, how the *true course* is found from the *compass course*, and the *compass course* from the *true*. We have now to show more fully what is meant by distance, and how it is measured.

The lengths of a degree of latitude and longitude at the equator are 60 nautical miles or 364,500 feet. Hence the length of one nautical mile is $= \frac{364500}{60} = 6075$ feet. The nautical mile is always taken as 6080 feet, not 6075.

When a ship loses sight of land, the principal method of ascertaining her place and directing her to her destination, is by making careful observations as to her course and distance. The *distance is the number of miles and tenths of a mile she runs*, and it is measured by the log line and half minute glass.

14. The Log, or Log Ship, is a flat piece of wood, in figure shaped into a sector of a circle. The broad part is loaded with lead to make it sit uprightly in the water; when so placed, it presents a sufficient amount of resistance to the water as practically to be considered stationary. To the log is fastened a line about 150 fathoms long, called the **Log Line,** divided into certain equal spaces called knots; because at the end of each of them there is either a piece of twine with knots in it reeved between the strands of the line, or some other mark showing how many spaces or knots run out in half a minute, which is the time generally allowed for making the necessary experiment to measure the rate of the ship.



THE LOG SHIP OR LOG.

This simple figure will show how the line is attached to the log ship. The upper cord of the three is fastened in its hole by a peg. The man who heaves the log, when the time is up, gives the line a smart jerk, and the peg comes out, when the log falls flat on the water, and is thus more easily drawn in again.

It is customary to use an ordinary sand glass that will run out in half a minute; although, in fact, any glass will do, so long as the sand glass runs out in the same fraction of a minute that the length of the knot is the fraction of a mile. The whole principle of the employment of the log, log line, and log glass is, that the length of each knot is the same part of a nautical mile as half a minute is of an hour.

Since half a minute is the $\frac{1}{120}$ part of an hour,
The knot must be the $\frac{1}{120}$ part of a nautical mile;
But a nautical mile is 6075 feet,
Hence a knot $= \frac{6075}{120} = 50{\cdot}625$ feet.

Or we may write

$$\frac{\text{The feet in one knot}}{\text{The feet in one mile}} = \frac{\text{the seconds the glass runs.}}{\text{the seconds in one hour.}}$$

It is customary to take the knot as 50 feet. Sailors commonly commence to count the knots at about 10 fathoms or more from the log (we should have mentioned that each knot is divided into tenths, which sailors call fathoms), so that the log, when it is thrown overboard, may be out of the disturbance of the sea lying in the ship's wake before commencing to count. This part of the line is called the *stray line*, and its termination is marked by a piece of red rag.

When thrown overboard, the line is unwound from the *reel* as fast as the ship moves. It shows the rate of progress the ship is making through the water; for half a minute being the same part of an hour as a knot is of a nautical mile, it is evident that whatever number of knots of the line the ship runs in half a minute she will run the same number of miles per hour, supposing the rate, as is generally done, uniform. We now see the force of the expression, "the ship is going 4 or 5 knots an hour." It really means that she is running 4 or 5 nautical miles per hour.

The distance given by heaving the log may be wrong, for three reasons: by an error in the glass, an error in the log line, or an error in both.

(*a*) When the log line is properly divided and the glass faulty.

(*b*) When the glass is true and log line faulty.

(*c*) When both are faulty.

(*a*) When the log line is properly divided and the glass runs out too quickly, it is evident that the proper number of knots will not have run out in the time, and therefore the rate of the ship will be put down less than it really is; on the contrary, if the glass runs too long more knots will run out and the estimated rate will be too great.

(*b*) If the glass be true and the log line faulty, we shall also have error. For if the glass be true and the line too short, more knots will run out in the given time than should do, and the distance estimated will be too great; while, on the contrary, if the knot be too long for the glass, an insufficient number will run out, and the estimated distance will be too short.

From the two cases it will be seen, (*b*) that *if the time remains fixed the distance found by the log will vary inversely as the length of the knot, i.e.*, if the knot be *too long* the distance will be *too short*, and if too short the distance will be too great; while, if the knot be correct (*a*) the distance found by an incorrect glass will vary directly as the glass, *i.e.*, if the glass runs too short distance will be too short, and *vice versa*.

(*c*) In the third case, when both are faulty, it is customary to find the true distance from the annexed formula:—

$$D = \tfrac{3}{5} \frac{dl}{t}$$

where D is the true distance,
d ,, erroneous distance,
t ,, time the glass runs,
l ,, length of the knot.

The formula is thus obtained: A glass runs out in t seconds, the line is wrongly knotted, and its length is l. Find the true distance (D) when it has been calculated that the ship has gone d miles.

(1) When the knot is correct and the glass wrong: we find the correct glass to the given knot by direct proportion, remembering that this is the case where the distance varies directly as the time.

The first step here is to find the length of the knot to the sand glass that will run out in t seconds of time.

Sec. Sec. Ft. in a knot.

$$\text{As } 3600 : t :: 6080 : \frac{t \times 6080}{3600} \text{ correct length.}$$

(2) When the log line varies and the glass remains

the same; we have then an inverse proportion, and to find the true distance, knowing the erroneous distance and the lengths of the knots in the two cases. The following inverse proportion exists according to the previous reasoning:—

$$\frac{\text{True knot}}{\text{Erroneous knot}} = \frac{\text{Erroneous distance}}{\text{True distance}}$$

Or, true knot : erroneous knot : : erroneous distance : true distance.

Substituting in this proportion the true length of knot just found—

$$\frac{6080 \times t}{3600} : l : : d : \text{D}$$

$$\therefore \text{D} = \frac{l\,d}{t} \times \frac{3600}{6080}$$

$$= \frac{3}{5} \times \frac{dl}{t}$$

$$\text{since } \frac{3600}{6080} = \frac{3}{5} \text{ very nearly.}$$

1. Find the length of a knot to a glass that runs out in 25 seconds.

One hour	Sec.	One mile
As 3600 :	25 : :	6080 : Ans.
		= $42\frac{2}{9}$ feet.

2. Find what glass I must use with a line knotted at every 55 feet.

One mile	Ft.	One hour.
As 6080 :	55 : :	3600 : Ans.
		= 32·56 seconds.

3. The apparent distance run at sea is 48 miles when the glass runs out in 33 seconds: what is the true distance run, length of knot being 54 feet? *Ans.* 47·1 or 46·5.

4. Explain the mode of estimating the distance a ship has run by the log. Supposing the log-line is wrongly divided, obtain a formula for finding the true distance run by it (1863).

Ans. $\text{D} = \frac{3}{5}\frac{dl}{t}$

5. How is a ship's rate of sailing estimated at sea? Describe the log fully (1864).

6. Given that the knot as shown by the log line is

erroneous, show how to correct the estimated distance run by a ship (1864).

7. What are the instruments used at sea to estimate the distance run by a ship during any time? Describe them fully, and show how to allow for any known errors in them (1866).

8. How is the distance run at sea found? If the length of the knot or the time in which the glass runs out be incorrect, how must the true distance be found?

9. The apparent distance run is 37 miles, the length of the knot is 53 feet, the glass runs out in 28 seconds, what is the true distance run (1865)? *Ans.* 41·4 or 42·021 nearly.

10. Explain the log line, and show to what errors it is liable (1865).

11. What is the true distance run by a ship when the distance by the log is 78 miles, the length of the knot is 47 feet, and the number of seconds the sand glass takes to run out is 27 (1865)? *Ans.* 80·4 or 81·46 nearly.

12. Describe the instrument commonly used for estimating the distance run at sea.

13. What should be the length of the knot on the log line when the sand glass runs out in 27 seconds, a nautical mile being assumed to be 6080 (1871)? *Ans.* 45·6 feet.

14. A log line is knotted every 45 feet, find what glass must be employed. *Ans.* 26·6 sec.

15. A glass that runs out in 35 seconds is employed on board a ship, what length of knot is used to correspond with it? *Ans.* 59·1 feet.

16. Describe the log, and show how it is employed to find the distance run. If the distance run by log is 315 miles, and the length of the log line is 47 feet, and the glass runs out in 32 seconds, what is the true distance run (1866)? *Ans.* 277·59 or 273·9.

17. How is the distance run by a ship at sea found? If the length of a knot on the log line is 47 feet, and the distance run is apparently 18 miles, what is the true distance run (1866), (glass runs out in 27 seconds)? *Ans.* 18·8 or 18·5.

18. Describe the log line, and show how it is divided (1867). The apparent distance run at sea is 48 miles when the glass runs out in 33 seconds, what is the true distance run (1866), (length of knot 56 feet)? *Ans.* 48·87 or 48·2.

19. What is meant by the terms *log ship, log line?* How is the log line attached to the log ship? What is the object of this mode of attachment? What is the stray line? Suppose a nautical mile to be 6080 feet, what must be the length of a knot on the log line when the glass runs out in 28 seconds (1869)? *Ans.* 47·3 feet nearly.

To many of these questions two answers are given; the

reason for such a proceeding is this :—One answer is obtained by substituting in the formula $D = \frac{3}{5} \cdot \frac{dl}{t}$ which is not exactly correct, but very near the true answer, as has been pointed out; the other answer has been found by first finding the proper length of knot to the glass given, and then the true distance by the proper proportion existing between true distance, erroneous distance, true knot, and erroneous knot; or, more rapidly, the answers may be found out by substituting in the formula

$$\frac{45}{76} \cdot \frac{dl}{t}$$

which was shown to be very nearly equal to

$$\frac{3}{5} \cdot \frac{dl}{t}$$

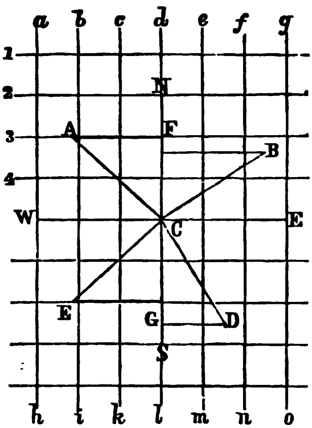
PLANE SAILING AND TRAVERSE SAILING.

15. Plane Sailing is sailing on the supposition that the earth is perfectly flat, that the meridians are right lines parallel to each other, and perpendicular to the equator, and that the parallels of latitude are right lines equal and parallel to each other, and parallel to the equator. It is not a strictly correct assumption to consider any part of the earth's surface a plane. Yet when the ship makes but little headway, the results obtained by plane sailing will be sufficiently correct to serve every useful purpose.

Let N E S W represent the horizon, 1 2 3 4, etc., parallels of latitude, and *a b c d*, etc., meridians. Suppose a ship to be at C ready to sail in the direction C A; when she arrives at A, then A C is the distance in nautical miles, F C the difference of latitude, A F the departure, A C F the course.

Given either two of these quantities we can find the third by the simplest definitions in trigonometry.

Here let me advise the teacher and student of navigation to avoid, if possible, all rules for plane sailing, and to trust entirely to the rudiments of trigonometry. For this end a lesson or two in that subject will be time thoroughly well spent. The following must be readily at the fingers' ends. Rules will be given, but we shall give more importance to showing how the following simple formulæ and definitions may be applied:—



Take triangle A F C—

$$\text{Sin. C.} = \frac{\text{A F}}{\text{A C}}, \text{ or Sin. course} = \frac{\text{departure}}{\text{distance}}$$

$$\therefore \text{ departure} = \text{distance} \times \text{Sin. course}$$

$$\therefore \text{ distance} = \frac{\text{departure}}{\text{Sin. course}}$$

$$= \text{departure} \times \text{Cosec. course}$$

$$\text{Cos. C.} = \frac{\text{F C}}{\text{A C}}, \text{ or Cos. course} = \frac{\text{difference of latitude}}{\text{distance}}$$

$$\therefore \text{ difference of latitude} = \text{distance} \times \text{Cos. course}$$

$$\therefore \text{ distance} = \frac{\text{difference of latitude}}{\text{Cos. course}}$$

$$= \text{diff. of lat.} \times \text{Sec. course}$$

$$\text{Tan. C.} = \frac{\text{A F}}{\text{F C}}, \text{ or Tan. course} = \frac{\text{departure}}{\text{difference of latitude.}}$$

The student must go over the above again and again till all the cases are thoroughly mastered, and he can shift and change them into every form, applying the formulæ to all the four triangles, C A F, C B F, C D G, and C E G.

A *rhumb line* is a curve on the earth's surface cutting every meridian it meets at the same angle. It is the track described by the ship while she remains on the same course. The length of this *rhumb* line is the DISTANCE.

16. **Distance** is the number of nautical miles a ship sails on a rhumb line, or it is the number of nautical miles on the rhumb line between the points of departure and arrival.

17. **Course.**—The path of a ship sailing on any single point of the compass is a rhumb line, and the angle which this line makes with each meridian is called the ship's course: it is measured from *north* or *south* towards *east* or *west*, either in points of the compass or degrees.

18. **Departure** is the distance that a ship has made good due *east* or *west* from the meridian it started from. The one following is a more precise definition.

If we imagine that the rhumb line intercepted between any two points on the earth's surface is divided into an infinite number of small equal parts, and that each part is the hypothenuse of a right-angled triangle, one side of which is the arc of a meridian, and the other side an arc of a parallel, then the sum of the arcs of the parallel forming the sides of the triangles is called the departure.

A lesson should now be given on the use of logarithms until the student thoroughly comprehends these three things:—

1. To perform multiplication by logarithms, you must add the logarithms of the multipliers together, and take out the logarithm of their sum.

2. To perform division by logarithms, you must subtract the logarithms of the number, and take out the logarithm of the remainder.

3. *To find the square root:* divide by 2 and take out the logarithm of the result.

Before entering on further explanations, a few examples are next worked out to create readiness in applying the formulæ given from trigonometry.

1. A ship sails from latitude 41° 15′ N. for 85 miles on a N.W. course, find the difference of latitude and departure.

Let the line C A represent the distance (85 miles) that the ship sailed; then drop the perpendicular A F upon the meridian running N. and S. and passing through the place C from which the ship started: this A F represents the departure, or the perpendicular distance between the meridian *d l* left and the meridian *b i* arrived at; while F C represents the difference of latitude, or the difference of latitude between the place left and the place arrived at; while angle A C F represents the course N.W. or 45° from N.

We will first find the difference of latitude; for this end, remembering the C F or the difference of latitude in our triangle A F C is related to the cosine of C, we at once start with

$$\text{Cosine course} = \frac{\text{C F}}{\text{A C}} = \frac{\text{difference of latitude}}{\text{distance}}$$

$$\therefore \text{difference of latitude} = \text{distance} \times \text{Cos. course}$$
$$= 85 \times \text{Cos. } 45^\circ$$

$$\begin{aligned} \text{Log } 85 \ldots\ldots &= 1{\cdot}929419 \\ \text{Log Cos. } 45 &= \underline{9{\cdot}849485} \\ \text{Log } 60{\cdot}1 \ldots &= \underline{1{\cdot}778904} \end{aligned}$$

$$\therefore \text{difference of latitude} = 60{\cdot}1 \text{ miles N.}$$

Now for departure. Departure is always connected with the sine:

$$\text{Sin. course} = \frac{\text{A F}}{\text{A C}} = \frac{\text{departure}}{\text{distance}}$$

$$\therefore \text{departure} = \text{dis.} \times \text{Sin. course.}$$
$$= 85 \times \text{Sin. } 45^\circ$$

$$\begin{aligned} \text{Log } 85 \ldots\ldots &= 1{\cdot}929419 \\ \text{Log Sin. } 45^\circ &= \underline{9{\cdot}849485} \\ \text{Log } 60{\cdot}1 \ldots. &= \underline{1{\cdot}778904} \end{aligned}$$

$$\therefore \text{departure} \ldots. = 60{\cdot}1 \text{ miles W.}$$

Here the departure is the same as the difference of latitude, which is always the case when the course is 45°, or N.W., N.E., S.E., and S.W.

As the ship sailed from lat................	41° 15′ 0″ N.
and the difference of latitude is 60·1 m. =	1° 0′ 6″ N.
∴ the ship is in latitude..................	42° 15′ 6″ N.

The 1° 0′ 6″ is obtained by dividing the 60′ by 60 miles in one degree, and multiplying the 1 by 6 (instead of 60, and then counting off one decimal place).

From this problem we get these two rules :—

To find difference of latitude: add log distance to log cos. course, and the sum is the logarithm of the difference of latitude.

To find departure: add log distance to log sine course, and the sum is the log of the departure.

The "latitude in" is found as in previous examples.

2. A ship sails from latitude 44° 30′ N., on an E.N.E. course till she comes to latitude 46° 10′ N., what distance has she run? and what departure has she made?

Difference of lat. is given for latitude from is 44° 30′ N.
latitude in is 46° 10′ N.
∴ difference of lat. is 1° 40′ N.
60
100 miles.

Difference of lat. is connected with cosine ∴ from triangle CFB

$$\text{Cos. course} = \frac{CF}{BC} = \frac{\text{difference of lat.}}{\text{distance}}$$

Here, as we know both course and difference of latitude, we can find the distance.

$$\therefore \text{Distance} = \frac{\text{difference lat.}}{\text{Cos. course}} = \text{difference lat.} \times \text{sec. course}$$
$$= 100 \times \text{sec. } 67° \, 30'.$$

Log 100........................= 2·000000
Log sec. 67° 30′...............= 10·417160
Log 261·3.....................= 2·417160*
∴ Distance is 261·3 miles E.N.E.

Now for *departure*, which is connected with the sine.

$$\text{Sin. course} = \frac{FB}{CB} = \frac{\text{departure}}{\text{distance}}$$

$$\therefore \text{Departure} = \text{distance} \times \text{sine course}$$
$$= 261{\cdot}3 \times \text{sine } 67° \, 30'$$

Log 261·3.....................= 2·417160*
Log sin. 67° 30′..............= 9·965615
Log 241·4.....................= 2·382775
∴ Departure = 241·4 miles E.

Hence we have a third rule, or the rule for finding the distance.

To find the distance: to log difference of latitude add log secant course, their sum is the logarithm of the distance.

3. A ship from latitude 44° 30′ N. sails S.S.E. till she has made 80 miles departure, what distance has she run? and what latitude is she in?

We have given course S.S.E., or S. 22° 30′ E., and distance 80 miles.

(1) Let the departure be found first, or sine in triangle C G D.

$$\text{Sin. C} = \frac{\text{G D}}{\text{C D}} = \frac{\text{departure}}{\text{distance.}}$$

$\therefore$ Departure = dis. × sin. course.
= 80 × sin. 22° 30′

Log 80.......................... = 1·903090
Log sin. 22° 30′.............. = 9·582840
Log 30·61...................... = 1·485930

$\therefore$ Departure = 30.61 miles E.

(2) The difference of latitude is to be found, or cos. in triangle C G D.

$$\text{Cos. C} = \frac{\text{C G}}{\text{C D}} = \frac{\text{difference of lat.}}{\text{distance}}$$

$\therefore$ Difference of lat. = dis. × cos. course
= 80 × cos. 22° 30′.

Log 80.......................... = 1·903090
Log cos. 22° 30′.............. = 9·965615
Log 73·91...................... = 1·868705

$\therefore$ Difference of lat. = 73·91 miles S.
60
54·60
= 1° 13′ 54″·6 S.

To find latitude in

Latitude from.........44° 30′ 0″ N.
Difference of lat....... 1° 13′ 54″·6 S.
Latitude in............43° 16′ 5″·4 N.

4. A ship sails from latitude 44° 30′ N. between S. and W. for 170 miles, till she finds herself in latitude 42° 55′ 44″ N.; what true course has she steered, and what departure has she made?

(1) The distance, 170 miles, is given.

(2) The difference of lat. is given { Lat. from...44° 30′ 0″ N.
Lat. in.......42° 55′ 44″ N.
Diff. of lat. 1° 34′ 16″ S.
60
94·26 miles S.

First, as we want the course and know the distance and difference of latitude, we must take the cosine in the triangle C E G to find it.

$$\text{Cos. C}=\frac{\text{C G}}{\text{C E}}=\frac{\text{difference lat.}}{\text{distance}}=\frac{94{\cdot}26}{170}$$

Log 94·26........................=1·974327
Log 170..........................=2·230449

Log cos. 56° 19′...............=9·743878
Course is S. 56° 19′ W.

Next, we want departure, so must use sine.

$$\text{Sin. C}=\frac{\text{E G}}{\text{E C}}=\frac{\text{departure}}{\text{distance.}}$$

$\therefore$ Departure = dis. × Sin. C.
= 170 × Sin. 56° 19′

Log Sin. 56° 19′...............=9·920184
Log 170..........................=2·230449

Log 141·4.......................=2·150633
$\therefore$ Departure = 141·4 miles W.

From this problem we have a rule for finding the course.

To find the course: from log difference of latitude substract log distance, mentally adding 10 to the index of the upper logarithm, the remainder is the log cosine of the course.

5. A ship sails from latitude 44° 30′ N., between N. and W. for 200 miles, when she finds her departure is 155 miles: find the true course on which she sailed, and the difference of latitude.

(*a*) The distance is given, 200 miles.
(*b*) The departure is given, 155 miles.

We must find course from these, and as we have the departure given, we must use sine in triangle C A F to find it.

$$\text{Sin. C}=\frac{\text{A F}}{\text{A C}}=\frac{\text{departure}}{\text{distance}}=\frac{155}{200}$$

Log 155..........................=2·190332
Log 200..........................=2·301030

Sin. 50° 48′ ....=9·889302
$\therefore$ Course is N. 50° 48′ W.

To find difference of latitude we use the cosine.

$$\text{Cos. } C = \frac{C\ F}{A\ C} = \frac{\text{diff. of lat.}}{\text{distance}}$$

$$\therefore \text{ diff. of lat.} = \text{dis.} \times \text{Cos. C.}$$
$$= 200 \times \text{Cos. } 50°48'$$

Log.............. = 2·301030
Log Cos. 50°48′ = 9·800737
Log 126·4....... = 2·101767
∴ diff. of lat. = 126·4 miles N.

To find latitude in

Latitude from	44° 30′ 0″	N.
Diff. of lat. 126·4 =	2° 6′ 24″	N.
Latitude in	46° 36′ 24″	N.

The 2° 6′ 44″ is found by dividing 126 by 60 and multiplying 4 by 60.

This sum gives another rule for finding the course.

To find the course: from log departure subtract log distance, mentally adding 10 to the index of the upper logarithm, the remainder is the log sine course.

6. A ship sails from latitude 44° 30′ 0″ N. between S. and E. till her departure is 80 miles and difference of latitude 169 miles. Find the true course on which she sailed, and the distance.

Here we have given difference of latitude 169 miles and departure 80 miles, from which we can find the course in triangle C D G.

$$\text{Tan. } C = \frac{G\ D}{G\ C} = \frac{\text{departure}}{\text{diff. of lat.}} = \frac{80}{169}$$

Log 80............ = 1·903090
Log 169..... ...... = 2·227887
Log tan. 25° 20′ = 9·675203
∴ Course is S. 25° 20′ E.

We can find distance by using either sine or cosine.

$$\text{Sin. } C = \frac{G\ D}{C\ D} = \frac{\text{departure}}{\text{distance}}$$

$$\therefore \text{ distance} = \frac{\text{departure}}{\text{Sin. C}} = \text{dep.} \times \text{Cosec. C}$$
$$= 80 \times \text{Cosec. } 25° \ 20$$

Log 80................ = 1·903090
Log Cosec. 25° 20′ = 10·368674
Log 186·9........... = 2·271764
∴ Distance is 186·9 miles.

Latitude from......... 44° 30′ 0″ N.
Diff. of latitude 169= 2° 49′ 0″ S.
Latitude in........... 41° 41′ 0″ N.

7. In this last example, if the variation be 31° 20′ E. and deviation 9° W., find the compass course.

True course.......25° 20′ l. of S.
Variation..........31° 20′ l.
56° 40′ l.
Deviation......... 9° 0′ r.
Compass course 47° 40′ l. or S. 47° 40′ E.

This problem supplies us with the third rule by which the course can be found.

To find course: from log departure subtract log difference of latitude, mentally adding 10 to the index of the upper logarithm; the remainder is the log of tan. course.

8. Required the compass course from A to B.

Lat. A 50° 20′ N. Varia. 23° 16′ W. Long. A 5° 15′ W.
Lat. B 51° 50′ N. Devia. 8° 4′ E. Long. B 5° 15′ W.

Here we have only difference of lat. = 1° 30′ = 90 m. N.
There is no difference of long. ∴ no departure.

∴ the true course is N.; distance 90 miles.

We have now to find the compass course.

True course...... N.
Variation.........23° 16′ r.
Deviation........ 8° 4′ l.
Compass course 15° 12′ r. or N. 15° 12′ E.

9. Required the magnetic course from A to B.

Lat. A 50° 22′ N., var. 20° 4′ W., lon. A 4° 8′ W.
Lat. B 48° 46′ N., dev. 7° 3′ W., lon. B 4° 8′ W.

Ans. S. 27° 7′ W.

10. A vessel sails from Cowes, latitude 50° 45′ 37″ N., longitude 1° 16′ 15″ W., on a true S. course for 54 miles: required the latitude and magnetic course when variation is 21° W. and deviation 12° 10′ E. *Ans.* Lat. in 49° 51′ 37″ N.
Mag. course S. 8° 50′ W.

11. A ship sails from latitude 41° 15′ N. for 125 miles on a

course N. $3\frac{1}{2}$ points W.; find the difference of latitude, departure, and latitude in.

Ans. Diff. lat. 96·6; dep. 79·3.
Lat. in 42° 51′ 36″ N.

12. A vessel is taken from latitude 44° 30′ N. on N.E. $\frac{1}{2}$-E. course till she comes to latitude 47° 40′ 18″ N., what distance has been run? and what departure made?

Ans. Dis. 300 m., dep. 231·9 m.

13. A ship from latitude 44° 30′ N. sails S.S.E. $\frac{1}{4}$-E. till she has made 103 miles departure, what distance has she run, and what is the latitude in?

Ans. 241 miles dis., diff. lat. 217·9 m.
Lat. in. 40° 52′ 6″ N.

14. Suppose a ship to sail from latitude 44° 30′ N. between S. and W. for 270 miles till she is in latitude 40° 25′ 54″ N., what is the true course steered and departure made good?

Ans. Course S.S.W. $\frac{1}{4}$-W., dep. 115·3 miles.

15. A ship sails from latitude 44° 30′, between N. and W., for 290 miles, when she finds her departure is 161·1 miles; find the true course on which she has sailed, and difference of latitude, and latitude in. *Ans.* Course N.W. by N.
Diff. lat. = 241·1 m., lat. in 48° 31′ 6″ N.

16. Suppose a ship to sail from latitude 44° 30′ 0″ N., between S. and E., till her departure is 148 miles, and difference of latitude 98·9 miles, find the true course on which she sailed, with the distance and latitude in.

Ans. Course S.E. by E., distance 178 miles.
Latitude in 42° 51′ 6″ N.

17. Required the compass course and distance from A to B. Given:

Lat. of A 51° 25′ N., var. 19° 20′ W., lon. 9° 29′ W.
Lat. of B 49° 16′ N., dev. 3° 16′ E., lon. 9° 29′ W.

Compass course S. 16° 4′ W.
Distance 129 miles.

18. Required the magnetic course and distance from A to B. Given:

Lat. of A 49° 53′ 37″ N., var. 2 points E., lon. 6° 20′ W.
Lat. of B 49° 0′ 37″ N., dev. 4° 15′ E., lon. 6° 20′ W.

Mag. course S. 26° 45′ E.
Distance 53 miles.

19. Show clearly how deviation and variation are allowed in finding a magnetic course.

20. Give a demonstration of the principles of plane sailing, with the definition of departure (1862). Explain the terms course and departure, and show that diff. lat. = dis. × Cos. course (1863 and 1868).

21. Prove that departure = distance × sin. course (1863).

22. Required the compass course and distance from A to B. Given:

Lat A 3° 18′ N., var. 2½ pts. E., lon. A 30° 25′ W. (1864).
Lat. B 12° 15′ S., lon. B 30° 25′ W.

Ans. Course S. 28° 7′ 30″ E.; distance 933 miles.

23. Draw a figure illustrating the definitions of the following terms in navigation:—(1) Rhumb line; (2) course; (3) distance; (4) difference of latitude; (5) departure (1864).

24. Prove that distance = departure × Cosec. course (1864).

25. Show by a figure what is meant by the terms distance, course, and departure (1865).

26. What is meant by the departure?

How is the departure estimated when a vessel sails on a given course from one point to another on the earth's surface (1868)?

27. Find the compass course and distance between A and B.

Given latitude A 23° 18′ S., longitude A 18° 20′ W.
" " B 31° 53′ S., longitude B 18° 20′ W.
Variation 1½ point W., deviation 3° W. (1868).

Ans. Course S. 19° 52′ 30″ W.; distance 515 miles.

28. Required the compass course and distance from A to B.

Lat. A 73° 30′ N., var. 1½ W., lon. A 43° 20′ E.
Lat. B 78° 41′ N., dev. 3° W., lon. B 43° 20′ E. (1865).

Ans. Course N. 19° 52′ 30″ E.; distance 311 miles.

29. How must I steer by compass when my true course is S.W. by W. ¾-W., variation 2½ points E., deviation ¾ point W., leeway ¼ point, wind S. by E. (1870)? *Ans.* S.W.

30. Define course, distance, and departure; express the departure in terms of the course and distance (1871).

31. If a ship sail from Oporto in latitude 41° 9′ N. 275 miles on a N.W. ½-W. course; required her departure and the latitude she has arrived at. *Ans.* Departure 212·6 miles, lat. in 44° 3′ 30″ N.

32. A ship sailed from latitude 41° 3′ S., W.N.W., till her departure was 145·1 miles; required the nautical distance she sailed and the latitude in.

Ans. Distance 157 miles, latitude in 40° 2′ 54″ S.

33. A ship being in latitude 10° 4′ S. sailed between N. and E. till she was in latitude 8° 12′ S., she made 80 miles departure, what was the true course and distance? (2) find the magnetic course, with variation 2 points E., deviation 9° W.

True course N. 35° 32′ E., distance 137·6.
Mag. course N. 22° 2′ E.

34. Suppose a vessel to sail south-westward till her departure is twice her difference of latitude, find the true course; (2) find magnetic course, with variation and deviation amounting to 1¾ points E. *Ans.* True S. 63° 26′ W.
Mag. S. 43° 44′¾ W.

35. Define the terms departure, nautical distance, true differ-

ence latitude, and difference longitude, and show that departure = true difference latitude × Tan. course (1872).

36. A ship sails from latitude 38° 4′ N., S.E. by S., till her departure is 50 miles; required the distance she has sailed and her latitude. Construct a figure (1872).

Distance 90 miles, difference of latitude 74·8 miles.
Latitude in 36° 49′ 12″ N.

37. A ship is in latitude 45° 18′ S., longitude 44° 25′ E., and sails in a W.S.W. direction until she is in latitude 47° 14′ S.: required the distance run and the departure (1872).

Distance 303·1, departure 280 miles.

38. A ship sailed from Cape Finisterre, latitude 42° 56′ 10″ N., longitude 9° 16′ 15″ W., on a course between W. and S. till her departure was 100 miles and difference of latitude 19·9; required the true course and distance.

Find the compass course and distance if the variation is 25° 10′ W., deviation 4° E. True course W. by S., distance 102 miles.
Compass course N. 80° 5′ W.

39. Why does a deviation table belonging to a ship vary from time to time.

TRAVERSE SAILING.

19. Traverse Sailing is the art of finding one course and distance that would bring a ship into the position she has arrived at by sailing on several courses with their respective distances. A ship can seldom, on account of land, rocks, shoals, contrary winds, etc., make directly for the port to which she is bound.

20. Traverse Tables.—Every good book of logarithms contains what is called a traverse table. It is thus calculated or constructed: all the distances from 1 mile to 300 are taken, and the departure and difference of latitude found for each with course 1°, 2°, 3°, etc., to 45° by plane sailing, these are all tabulated and called the traverse tables. The first page has the distances from 1 to 300 miles, with the difference of latitude and departure for 1° as a course. But inasmuch as the sine of an angle is equal to the cosine of its complement, the difference of latitude for 1° will be the departure for 89°, and the departure for 1° will be the difference of latitude for 89°.

Hence at the bottom of page 1 we have 89°, or page 1° stands for page 89°, but at bottom of latitude column is departure, at bottom of departure column is latitude. So page 2° also answers for 88°. Hence only 45° pages complete the traverse table. As well as making a table for the degrees, there is also a traverse table for the points, which is often very convenient. As a matter of fact, sailors seldom sail to degrees, but always reckon their course in points and quarter points. In plane sailing, any two quantities being given, it is possible by the traverse tables to find all the others without calculating them. Hence their great utility, that all the calculations in *plane* sailing can be done by looking out the quantities in the table book. The examples we have worked out and given in this chapter can be done without any of the calculations we have used in the previous chapter, by merely looking out the answers in the traverse table. Hence students should accustom themselves to find all their answers in plane sailing (it will afterwards be shown that the same thing can be done with parallel sailing) from the tables to check their working.

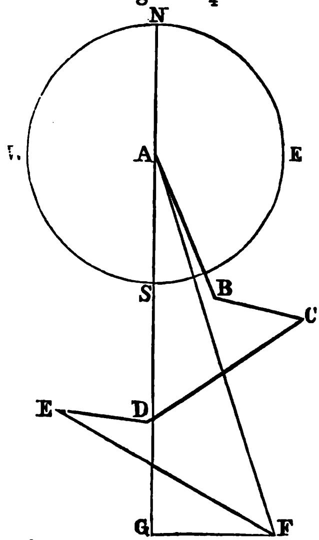
To resolve a traverse or compound course is then to reduce several courses and distances to a single course and distance.

First, we will show how to resolve a traverse geometrically, and then by the usual method of employing the tables.

1. A ship sails from latitude 51° 25′ N., longitude 8° 12′ W.; S.S.E. 30; E.byS. 18; S.W.byW. 36; W.¾-N. 14; and S.E.by E.¼-E. 46 miles: required the equivalent course and distance, and the latitude and longitude of the place arrived at (1872).

Let A be the centre of the compass. (1) The ship sails S.S.E. 30 miles. The line A B is drawn S.S.E., so that angle G A B is 22° 30′, then A B is marked off as 30 miles. The scale used is 36 miles to the inch. (2) Then she goes E.byS. 18 miles, so B C is drawn E.byS., and B C cut off 18 miles from the same scale. (3) The ship now sails S.W.byW. 36 miles, therefore C D is drawn five points right of S., and C D taken by scale as

36 miles. (4) The ship next goes W.¾-N. 14, so we draw the line D E at an angle W.¾-N. or 81° 33′ 45″ left



SCALE 36 MILES TO 1 INCH.

of N., and cut off D E 14 miles by scale. (5) Lastly, the ship turns and sails S.E.byE.¼-E., or 5¼ points left of S., for 46 miles, so we draw E F in that direction, and make E F equal to 46 miles. This leaves the ship at F, now drop a perpendicular from F upon the meridian left A G, when F G will be the departure, which is by scale 25 miles. A G is the difference of latitude, by scale 72 miles, while G A F is the course. After measuring this angle we find it to be S. 19° E., and the distanee A F is from the scale 77 miles.

Results: Difference of latitude, 72 miles. Course, S. 19° E.
Departure,............... 25 miles. Distance, 77 miles.

We have now to show how to work out this traverse by the tables.

Courses.	Dist.	Diff. of Lat.		Departure.	
		N.	S.	E.	W.
S.S.E. - - - 2 pts.	30		27·7	11·5	
E.byS. - - - 7 pts.	18		3·5	17·7	
S.W.byW. - 5 pts.	36		20		29·9
W.¾-N. - - 7¼ pts.	14	2·1			13·8
S.E.byE.¼-E. 5¼ pts.	46		23·6	39·5	
		2·1	74·8	68·7	43·7
			2·1	43·7	
	Diff. lat. S.		72·7	25	Dep. E.

(*a*) Draw lines forming six columns: in the first, or left hand column, place the courses in their proper order, and one under the other. In the second column place distances opposite their proper courses. At the head of the next two columns, put difference of latitude and N. and S., to indicate north and south; over the two remaining put departure E. and W., for east and west.

(*b*) Open the table book at page headed "Difference of latitude and departure for 2 points;" look down the distance or first column on the left hand for 30; opposite 30 is found 27·7 and 11·5, which are the difference of latitude and departure for 30 when sailing two points from N. or S.; the 27·7 must be placed in the column headed S., and the 11·5 in the column headed E., because the course is S. and E.

For the *second course* E.byS., turn to the page 7 points (marked 1 point at top). Look in the first column on the left hand for distance 18, where 17·7 and 3·5 are placed opposite the 18; but as your course is at the bottom you must read these 3·5 difference of latitude, and 17·7 departure, and place the 3·5 under S. and 17·7 under E.

Third course: turn to page 5 points, and opposite the 36 we read the 20 and 29·9 from right to left, not as they

are placed in the tables, because the course is at the bottom of the page; place the 20 under S. and 29·9 under W.

Fourth course.—Because beginners are so apt to make mistakes in taking out the difference of latitude and departure when the course is at the bottom of the page, we repeat the process at the risk of monotony. Turn to 7¼ points at bottom of page, where, in first left hand columns opposite 14, is seen 13·8 and 2·1, *which we read* 2·1 *and* 13·8, *since the course is at the bottom of the page,* and place them under N. and W. respectively.

Fifth course, 5¼ points, is also taken out from bottom, and opposite 46 we read from right to left 23·6 and 39·5, and place them under S. and E.

(*c*) Add up each column, and subtract the less from the greater in each pair. In this case subtract the 2·1 N. from 74°·8 S., leaving on the whole a total difference of latitude of 72°·7 S. Now subtract the 43·7 from 68·7, leaving 25 miles as the departure towards the E.

(*d*) Turn to the traverse table again and find the two numbers 72·7 and 25 opposite each other in the difference of latitude and departure columns. A little practice will soon accustom one to turn to the proper page directly, but we may always notice this: if the *difference of latitude* is the *greater* of the two numbers, the course is at the *top* of the page; while if *departure* is *greater,* the course is at the bottom of the page. Looking in the traverse table, then, we find 72·7 and 25, or the nearest numbers to them 72·8 and 25·1, together on the page for 19°, and immediately to the left of them is 77 in the distance column. We therefore write down

Course, - - - S. 19° E.; distance, 77 miles.
Difference of latitude, 72·7 miles; departure, 25 miles.

The student must notice how far this agrees with the previous solution.

We have now to find the latitude and longitude. Latitude is simply found; and it is rather unusual to find the longitude at this early stage, but the process is so simple and mechanical that a child can comprehend it; therefore it will be introduced here

	Latitude	Mid-latitude.	Longitude.
Lat. from	51° 25′ 0″N.	51° 25′ 0″N.	Lon. from 8° 12′W.
Diff. lat. 72·7 =	1° 12′ 42″ S.	50° 12′ 18″N.	Diff. of lon. 40′E.
Lat. in	50° 12′ 18″N.	2)101° 37′ 18″	Lon. in....7° 32′W.
		50° 48′ 39″	
		90° 0′ 0″	
Co-mid-latitude, -		39° 11′ 21″	

Apply the difference of latitude 72·7 to the latitude from, and we have the latitude in 50° 12′ 18″ N.

We next add the latitude *from* and *in* together, and take half the sum, this gives us the middle latitude; we subtract it from 90°, this gives the co-mid-latitude.

Co-mid-latitude is the distance of a place midway between two given latitudes from the nearest pole.

With this co-mid-latitude 39°, we go to the traverse tables, and on page 39° we find the departure 25 *miles in the departure column* (nearest is 25·2); corresponding to this is 40 in the distance column: this we apply to the longitude eastwards, because the departure is east, and it gives us longitude in 7° 32′ W.

2. A ship sails from latitude 20° 44′ S., longitude 40° 27′ 8″ E., on the following courses and distances, find the position of the ship at the end of the time, and the compass course if the variation is 56′ E., and deviation 8° 49′ W.

S.S.W. 112 miles; S.byE. 86 miles; S.byW. 86 miles.
S.S.E. 112 miles; S. 50 miles; S.E.byS. 90 miles.

Courses.	Dist.	Diff. lat.		Departure.	
		N.	S.	E.	W.
S.S.W.	112		103·5		42·9
S.byE.	86		84·3	16·8	
S.byW.	86		84·3		16·8
S.S.E.	112		103·5	42·9	
S.	50		50		
S.E.byS.	90		74·8	50·	
		Diff. lat.	S. 500·4	109·7	59·7
				59·7	
				50	Dep. E.

Course, S. 6° E.; distance, 502 miles.

As before, the whole of the above is taken from the tables; but when we come to look for course and distance, it is found that we have no difference of latitude in the table book higher than 300 miles, and we want 500; the difficulty is overcome by taking the halves of 500·4 and 50, viz., 250·2 and 25, and finding them in the tables, the nearest will be found under 6° to be 249·6 and 26·2; we therefore take the distance corresponding (251) and double it, which gives 502 as the distance and course S. 6° E. We will next find the latitude and longitude, and then show how we may get the answers above a little nearer, although they are already sufficiently near for all practical purposes.

	Latitude.	Mid-latitude.		Longitude.
Lat. from............	20° 44′ 0″S.	20° 44′ 0″S.		20° 44′ 0″E.
Diff. lat. 500·4 ...	8° 20′ 24″S.	29° 4′ 24″S.		0° 55′ 0″E.
Lat. in...............	29° 4′ 24″S.	2)49° 48′ 24″	Lon. in	21° 39′ 0″E.
	Mid-lat.	24° 54′ 12″		
		90° 0′ 0″		
	Co-mid-lat.	65° 5′ 48″		

At the risk of sameness, we will again show how the latitude and longitude have been found.

First, the difference of latitude 500·4 miles = 8° 20′ 24″ are applied to the "latitude from" towards the S., which brings us farther S. from the equator.

Second, the co-mid-latitude is found as before. We take the 65° and find it in the traverse table at the bottom; next in the departure column (from the bottom) we find departure 50 (nearest 49·8) on page 65°, and see that the distance corresponding to it is 55. This 55 miles we apply to the longitude, and find the ship is in 21° 39′E. longitude.

To find the compass course:

True course,	6° 0′ l. of S.
Variation,	0° 56′ l.
	6° 56′ l.
Deviation,	8° 49′ r.
Compass course S.	1° 53′ W.

To find the course and distance by plane sailing:

$$\text{Tan. course} = \frac{\text{dep.}}{\text{diff. lat.}} = \frac{50}{500 \cdot 4}$$

$$\begin{aligned}
\text{Log } 50 &= 1\cdot698970 \\
\text{Log } 500\cdot4 &= 2\cdot699317 \\
\text{Tan. } 5^\circ\ 42' &= \overline{8\cdot999653}
\end{aligned}$$

∴ Course is S. 5° 42′ E.

$$\text{Cos. course} = \frac{\text{diff. lat.}}{\text{dist.}}$$

∴ Distance = diff. lat. × Sec. course

$$\begin{aligned}
\text{Log } 500\cdot4 &= 2\cdot699317 \\
\text{Log Sec. } 5^\circ\ 42' &= 10\cdot002153 \\
\text{Distance } 502\cdot8 &= \overline{2\cdot701470}
\end{aligned}$$

It will thus be seen how little the two sets of answers differ, which ought to be the case.

3. A vessel sails on the following courses and distances from lat. 46° 27′ 36″ N., lon. 61° 56′ 8″ E.; find course, distance, lat. and lon. in. E. 45 m.; E.byS. 50 m.; E.byN. 30 m.; N.E. 45 m.; N.byW. 30 m.; and N.E.byE. 27 m.

Courses.	Dist.	Diff. lat.		Departure.	
		N.	S.	E.	W.
E.	45			45	
E.byS.	50		9·8	49	
E.byN.	30	5·9		29·4	
N.E.	45	31·8		31·8	
N.byW.	30	29·4			5 9
N.E.byE.	27	15		22 4	
		82·1	9·8	177·6	5 9
		9·8		5·9	
		72·3 diff. lat. N.		171·7	Dep. E.

Course, N. 67° E.; distance, 186 miles.

	Latitude.	Mid-latitude.		Longitude.
	46° 27′ 36″ N.	46° 27′ 36″ N.		61° 56′ 8″ E.
Diff. lat.	1° 12′ 18″ N.	47° 39′ 54″ N.		4° 12′ 0″ E.
Lat.	47° 39′ 54″ N.	2)94° 7′ 30″	Lon.	66° 8′ 8″ E.
		47° 3′ 45″		
		90° 0′ 0″		
	Co-mid-lat.	42° 56′ 15″		

Now arcs which subtend equal angles, are to one another as the radii of the circle of which they are arcs;

$$\therefore \frac{\text{arc } ab}{\text{arc AB}} = \frac{a\text{D}}{\text{AO}} = \frac{a\text{D}}{a\text{O}} \because \text{A O} = a\text{O both being radii of the sphere.}$$
$$= \text{Sin. } a\text{OD}$$
$$= \text{Cos. } a\text{OA}$$
$$\therefore \frac{\text{arc } ab}{\text{arc AB}} = \text{Cos. } a\text{OA}$$

but arc ab is the departure or meridian distance, arc A B is the difference of longitude, and angle a O A is latitude,

$$\therefore \text{Cos. } a\text{OA} = \text{Cos. lat.}$$
$$\therefore \frac{\text{mer. dis.}}{\text{diff. lon.}} = \text{Cos. lat.}$$
$$\therefore \text{mer. dis.} = \text{Cos. lat.} \times \text{diff. lon.}$$
$$\therefore \text{diff. lon.} = \frac{\text{mer. dis.}}{\text{Cos. lat.}} = \text{mer. dis.} \times \text{sec. lat.}$$

If M = mer. dis., L = diff. long., we get the formula M = L × cos. l, by which all questions in parallel sailing may be solved.

1. A vessel sails from A to B, required the compass course and distance. Given:

Lat. A 38° 42′ N.; var. 21° 10′ W.; lon. A 9° 9′ W.
Lat. B 38° 42′ N.; dev. 8° 12′ E.; lon. B 19° 10′ W.

As both places are on the same parallel of latitude, we have to sail on a parallel and go W. from a place (Lisbon) in W. longitude to one further west.

Lat. 38° 42′ N. { Lon. A 9° 9′ W.
{ Lon. B 19° 10′ W.
Diff. lon. 10° 1′ W.
60
601

Mer. dis........... = diff. lon. Cos. lat.
M. .... = 601 × Cos. 38° 42′
Log 601............ = 2·778874
Log cos. 38° 42′... = 9·892334
Log 469............ = 2·671208
∴ Meridian distance is 469 miles.

Now for compass course, true course is due W.		90° 0′ 0″ l. of N.
	Variation W.	21° 10′ 0″ r.
		68° 50′ 0″ l.
	Deviation	8° 12′ 0″ l.
		77° 2′ 0″ l. of N.
	.. Compass C., N.	77° 2′ 0″ W.

Ans. Distance 469 miles C. C., N. 77° 21′ W.

From this problem the annexed rules for parallel sailing are deduced.

(1) *To find meridian distance*—

To log difference of longitude add log cosine of the latitude, omitting 10 from the index. The sum is the logarithm of the meridian distance.

From problem (3) following.

(2) *To find latitude* in parallel sailing, given meridian distance and difference of longitude.

From log meridian distance, subtract log difference of longitude, mentally adding 10 to the index of the upper logarithm. The remainder is log Cos. latitude.

(3) *To find difference of longitude* (as in Ex. 4.)—

To log meridian distance add log secant latitude, omitting 10 from the index. The sum is log. difference of longitude.

2. Find the length of a degree of longitude in latitude 45°.

Here difference of longitude is 60′.

$$M = L. \text{ Cos. } l.$$
$$M = 60 \times \text{Cos. } 45$$

Log 60 = 1·778151
Log Cos. 45 = 9·849485
Log 42·42 = 1·627636

Ans. 42·42 miles.

3. Find in what latitude the length of a degree of longitude is 45 miles.

$$M = L. \text{ Cos. lat.}$$
$$45 = 60 \times \text{Cos. } l.$$
$$\text{Cos. } l. = \frac{45}{60}$$

Log 45........... = 1·653213
Log 60........... = 1·778151
Log Cos. 41° 25′ = 9·875062

Ans., lat. 41° 25′

4. In lat. 50° 35′ N. I sail due E. 340 miles, how much do I change my longitude?

$$M = L. \text{ Cos. } l.$$
$$340 = L. \text{ Cos. } 50° 35'$$
$$\therefore L = 340 \times \text{Sec. } 50° 35'$$

$$\begin{aligned} \text{Log } 340 \ldots &= 2{\cdot}531479 \\ \text{Sec. } 50° 35' &= 10{\cdot}197257 \\ \hline \text{Log } 535{\cdot}4 &= 2{\cdot}728736 \end{aligned}$$

6,0)535′·9

Ans. 8° 55′ 54″ of longitude.

5. Suppose the longitude from which the ship started is 140° 56′ E., let us now find the longitude of the ship.

Lon. from	140° 56′ 0″ E.
Diff. of lon.	8° 55′ 54″ E.
Lon. in	149° 51′ 54″ E.

6. A and B lie on the same parallel of 34° 33′ S.
Give lon. of A 18° 24′ E.
Give lon. of B 2° 9′ W.
What is the distance between them in nautical miles (1868)?

Lat. 34° 33′ S. Lon. A 18° 24′ E.
B 2° 9′ W.
Diff. lon. 20° 33′
60
1233

$$M = L. \text{ Cos. } l.$$
$$= 1233 \times \text{Cos. } 34° 33'$$

$$\begin{aligned} \text{Log } 1233 \ldots\ldots\ldots &= 3{\cdot}090963 \\ \text{Log Cos. } 34° 33' &= 9{\cdot}915733 \\ \hline \text{Log } 1015 \ldots\ldots\ldots &= 3{\cdot}006696 \end{aligned}$$

Distance between A and B is 1015 miles.

7. What are the compass courses and distances of a ship that makes 54 miles westing, then 80 miles northing, from Swan River, lat. 32° 3′ S., lon. 115° 45′ E., var., 18° E., dev. 4° 5′ E., in the first case, and 3° 10′ W. in second.

$$M = L. \text{ Cos. } l.$$
$$54 = L. \text{ Cos. } 32° 3'$$
$$\therefore L = 54 \times \text{Sec. } 32° 3'$$

$$\begin{aligned} \text{Log } 54 &= 1{\cdot}732394 \\ \text{Log Sec. } 32° 3' &= 10{\cdot}071817 \\ \hline \text{Diff. lon. } 63{\cdot}71 &= 1{\cdot}804211 \end{aligned}$$

Lon. from	115° 45′ 0″ E.
Diff. lon.	1° 3′ 42″ W.
Lon. in	114° 41′ 18″ E.

Being in lat. 32° 3′ S. and lon. 114° 41′ 18″ E., the ship went 80 miles north, now to find the lat. in

Lat. from	32° 3′ 0″ S.
Diff. lat.	1° 20′ 0″ N.
Lat. in	30° 43′ 0″ S.

(1) Compass course.		(2) Compass course.	
W is	90° 0′ 0″ r. of S.		0° 0′ 0″ from N.
Var. E.	18° 0′ 0″ l.	Var. E.	18° 0′ 0″ l.
	72° 0′ 0″ r		18° 0′ 0″ l.
Dev. E.	4° 5′ 0″ l.	Dev. W.	3° 10′ 0″ r.
C. C.	67° 55′ 0″ r. of S.	C. C.	14° 50′ 0″ l. of N.

Two courses S. 67° 55′ W., and N. 14° 15′ W.

8. With what velocity does the earth travel at the equator?

Velocity is generally reckoned in feet per second, but our units in this answer will be *miles* and hours.

In 24 hours the earth moves through 360°

In 1 hour, ,, ,, $\frac{360}{24} = 15°$

In 1 degree there are 60 miles.
In 15 degrees there are $60 \times 15 = 900$ miles.

And this is the velocity of the earth in miles per hour at the equator. If we calculate for latitude 60° we shall have 450 miles, thus—

$$M = L. \text{ Cos. lat.}$$
$$M = 900 \times \text{Cos. } 60°$$

Log 900	= 2·954243
Log Cos. 60°	= 9·698970
Vel. is 450	= 2·653213

9. Prove that *meridian distance* is equal to *difference of longitude* multiplied by the *cosine of the latitude* (1863).

10. Required the compass course and distance from A to B (1865). Given:

Lat. A 52° 15′ S.; var. $1\frac{1}{2}$ points W.; lon. A 37° 30′ W.
Lat. B 52° 15′ S.: dev. 8° 50′ W.; lon. B 48° 18′ W.

Ans. Course N. 64° 17′ 30″ W.; distance 396·7 miles.

11. What is meant by a parallel of latitude? and show that the length of a degree of longitude in latitude *l* is to the length of a degree of longitude at the equator as Cos. *l.* : 1. In what latitude are the lengths of a degree of longitude 30 and 20 miles respectively (1864).

Ans. 60° and 70° 31′ 43″

12. Show that in parallel sailing dis. = diff. lon. × Cos. lat. (1865).

In travelling 35 nautical miles on the parallel 55° 25′ N., how much do I change my longitude (1867)?

Ans. 61′·6 ; or 1° 1′ 36″

13. A and B lie on the parallel of 58° 30′ N.

Given lon. A 15° 12′ E.
Given lon. B 13° 18′ W.

What is the distance between them in nautical miles (1868)?

Ans. 893·4 miles.

14. Define a great circle and a small circle of a sphere, giving an example of each. What connection is there between the tropic of cancer and the arctic circle (1870)?

15. Find the true course and distance from A to B.

Lat. of A 54° 25′ S.; lon. A 15° 30′ E.
Lat. of B 54° 25′ S.; lon. B 9° 15′ W.

Ans. Course W., distance 864·1 miles.

16. What are the true course and distance of a ship which makes 65 miles southing and 75 miles easting (1870)?

S. 49° 5′ E. 99·24 miles.

17. What are the compass course and distance from A to B? Given:

Lat. A 25° 18′ S.; lon. A 145° 12′ E.; var. $1\frac{1}{4}$ pts. E.
Lat. B 25° 18′ S.; lon. B 136° 18′ E.; dev. 11° 25′ W.

Ans. Course S. 87° 21′ 45″ W.; distance 482·7 miles.

18. How are the compass course and distance found when a ship sails (1) on a parallel? (2) on a meridian? Prove the rules where necessary (1865).

19. Required the compass course and distance from A to B (1866).

Lat. A 28° 40′ N.; var. $1\frac{3}{4}$ pts. W.; lon. A 2° 20′ E.
Lat. B 28° 40′ N.; dev. 8° 50′ E.; lon. B 4° 10′ E.

Ans. Course S. 79° 8′ 45″ E.; distance 96·5 miles.

20. A ship is in latitude 35° 30′ S., longitude 27° 28′ W., and is to sail in a due E. direction 301 miles, what is the compass course she must steer and lon. in, variation $1\frac{3}{4}$ points E, deviation 8° 50′ E. (1866)?

Ans. Course N. 61° 28′ 45″ E.; lon. in 21° 18′ 18″ W.

21. A ship in latitude 49° 35′ N., longitude 8° 40′ W., sails due S. 15 miles, and then alters her course due E. for 25 miles, what are her latitude and longitude in? What course must she be steered by the ship's standard compass, allowing 25° 49′ W. for

deviation in the first position of her head, and 12° 50′ E. in the second (1869)?

Ans. Lat. in 49° 20′ N.; lon. in 8° 6′ 39″ W.
Courses S. 25° 49′ W. and N. 77° 10′ E.

22. How far must a ship sail due E. in latitude 70° to change her longitude 5°.

Ans. 102·6 miles.

23. In what latitude is it that every time a ship goes 8 miles she changes her longitude 9·5 miles.

Ans. 32° 38′ (lat.)

24. A ship changes her longitude 1° when she has only sailed 0 miles, what is the latitude?

Ans. 33° 33′ (lat.)

MIDDLE LATITUDE SAILING.

30. IN parallel sailing we showed that the meridian distance was equal to the difference of longitude multiplied by the cosine of the latitude. Middle latitude sailing uses parallel sailing to correct the errors in plane sailing, which is in error from the fact that plane sailing assumes the earth to be a plane. By combining, then, parallel and plane latitude sailing, we *partially* correct the errors introduced by this assumption.

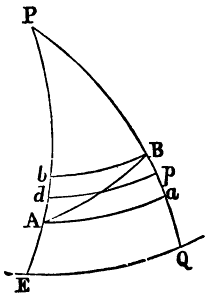
(*a*) When a ship sails due north or south, she, keeping on the same meridian, merely alters her latitude without producing any effect on the longitude; the distance she runs is her difference of latitude, which being properly applied to the "latitude from," gives the "latitude in."

(*b*) When a ship sails due east or west she keeps upon the same parallel and so alters not her latitude, she only changes her longitude; the difference of longitude she has made is determined by the equation $M = L \text{ Cos. } l$; so, knowing the distance she has sailed we can find the longitude in, or knowing the meridian left and arrived at, we can find the difference of longitude.

(*c*) When a ship sails neither on a parallel nor on a meridian, but on an obliaue course, or on a rhumb line

at an angle with the meridians, she alters both her latitude and longitude.

It is the province of middle latitude sailing to show how in this latter case the *course, distance, departure, difference of latitude, latitude in,* and *longitude in,* are found when certain of these quantities are given.



In parallel sailing we have had M = L × Cos. *l*, in middle latitude sailing we write this Dep. = diff. lon. × Cos. mid-lat., or mer. dis. = diff. lon. × Cos. mid-lat. The adaptation of the formula is founded on the consideration that the arc of the parallel in the middle latitude of two places, intercepted between their two meridians, is very nearly equal to the departure between the two places.

Let P be the pole of the earth. A and B two places on the earth's surface. P E and P Q the meridians passing over the two places A and B. E Q the arc of the equator intercepted between A and B.

Let A *a* and B *b* be arcs of the parallels of latitude passing through A and B, and *d p* the parallel of latitude passing through the middle place between A and B.

Then, if a ship be supposed to sail on a rhumb line from A to B, her departure will evidently be greater than B *b*, but less than A *a*, and is in many cases very nearly equal to *d p*, the departure in the middle latitude.

Hence $dp = $ E Q Cos. E d.
∴ *dep.* or *mer. dis.* = diff. long. × Cos. mid-lat.

This formula is not exactly correct, but is sufficiently so for all practical purposes. We will show presently when the greatest amount of error exists. There is, however, some third parallel between those passing through A and B, by using which, to compute the distance between the two meridians, will give the exact

distance required. At a great distance from the pole, or near the equator, and when the difference of latitude is small, or where the course is greater than 45°, this third parallel is found nearly in the middle, between the two, but always a little *nearer* the pole. For this reason, and from an inspection of our figure, we come to these conclusions, that middle latitude sailing should not be used in high latitudes when the course is near the meridian, nor when the places are one on one side of the equator, and the other on the other; but it may be employed with exactitude when the places are on the same side of the equator, in low latitudes, and when the course is greater than 45°.

We now repeat succinctly much that has been said, and let the reader, if he does not thoroughly understand what we now say, begin the chapter again. No time will be lost by so doing.

The departure made by sailing on a rhumb line between two places on the earth's surface, is equal to the distance of the meridians of the two places reckoned on the parallel of latitude, which lies midway between the parallels on which the two places lie. And although this supposition is not strictly correct, for the mean of the cosines of the two latitudes is not exactly the cosine of the arithmetic mean of those latitudes, nor is the departure on the rhumb cutting the two meridians precisely equal to that in the mean position, but it is equal to that in a somewhat higher latitude; yet, when the places are in low latitudes, or not far from the equator, and when the parallels are close to each other, the error arising from the assumption made in middle latitude sailing is very small, and does not sensibly affect the nautical conclusions drawn from it.

We will now indicate the chief formulæ used in middle latitude sailing, and then give a few illustrations drawn from examination papers. Before proceeding, let us insist upon the necessity, in all cases, of drawing the triangle before any attempt is made to solve the problems;

and that it is most needful for a firm grounding in this subject for the student to pick out the rules from the triangle and not from his memory.

$$\text{Mer. dis.} = \text{diff. lon.} \times \cos. \text{lat.}$$

$$\text{Dep. or mer. dis.} = \text{diff. lon.} \times \cos. \text{mid-lat.} \quad \text{(Z)},$$

By plane sailing,

$$\text{Tan. course} = \frac{\text{dep.}}{\text{diff. lat.}}$$

$$\therefore \text{Tan. course} = \frac{\text{diff. lon.} \times \cos. \text{mid-lat.}}{\text{diff. lat.}} \quad \text{(A)}.$$

$$\text{From (Z) diff. lon.} = \text{dep.} \times \sec. \text{mid-lat.}$$

$$\text{By plane sailing, dep.} = \text{dis.} \times \sin. \text{course.}$$

$$\therefore \text{diff. lon.} = \text{dis.} \times \sin. \text{C.} \times \sec. \text{mid-lat.} \quad \text{(B)}.$$

Every problem in middle latitude sailing will resolve itself into one of the three cases, Z, A, or B, but the most important are A and B. It is as well to call attention to the circumstance, that the aim in all we have under consideration is to show how the longitude may be obtained with the greatest accuracy.

It is a common practice with writers on navigation to lay down rules showing when middle latitude sailing should be used, and when not; and then to go directly in their examples and illustrations and fall into the very error themselves, taking no notice of the rules laid down. In our illustrations we will try to avoid this error. Again, in the government examinations it is a very common practice to ask for the course and distance from a certain latitude and longitude to another differing both in latitude and longitude, leaving it to the option of the student whether he will work by middle latitude or Mercator's sailing. The safest way in all these cases is to use Mercator's sailing. But it is open to the student to exercise a little discrimination. Generally, if the latitudes are high, use Mercator's sailings; but if low, and the difference of longitude is greater than the difference of latitude, or it would have been more correct to say, the meridian distance greater than the difference of latitude, the student may, if he prefer, solve the question by middle latitude sailing.

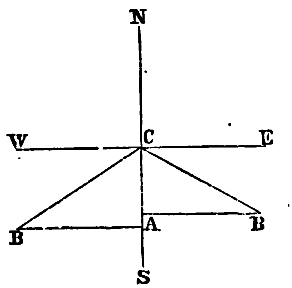
1. Required the compass course and distance from Cape Negro, latitude 15° 50′ S., longitude 11° 30′ E., to Cape St. Roque, latitude 5° 15′ S., longitude 34° 30′ W. (1864). This question is incomplete, we complete it thus: variation 19° 10′ W., deviation 7° 15′ W.

	Diff. lat.	Mid-lat.		Diff. lon.
Cape Negro, lat.	15° 50′ S.	15° 50′ S.	Longitude	11° 30′ E.
Cape St. Roque, ,,	5° 15′ S.	5° 15′ S.	,,	34° 30′ W.
	10° 35′	2)21° 5′		46° 0′ W.
	60	10° 32½′ mid-lat.		60
Miles,	635 S.		Diff. lon.	2760 W.

To find course:

$$\text{Tan. C} = \frac{\text{A B}}{\text{A C}} = \frac{\text{dep.}}{\text{diff. lat.}} = \frac{\text{diff. lon.} \times \text{Cos. mid-lat.}}{\text{diff. lat.}}$$

Log 2760 diff. lon....................	3·440909
Log Cos. 10° 32½′ mid-lat..........	9·992608
	13·433517
Log 635 diff. lat.....................	2·802774
Log tan. 76° 49′ course............	10·630743



$$\text{Cos. C} = \frac{\text{A C.}}{\text{B C.}}$$

$$\therefore \text{Cos. C} = \frac{\text{diff. lat.}}{\text{dis.}}$$

$$\therefore \text{distance} = \text{diff. lat.} \times \text{sec. C.}$$

Log 635 diff. lat................	2·802774
Sec. 76° 49′ course, ...	10·641936
Log 2784 dist....................	3·444710

True course S. 76° 49′ W. is	76° 49′ r. of S.
Variation, ...	19° 10′ r.
Deviation, ...	7° 15′ r.
	103° 14′ r. of S.
	180° 0′
	76° 46′ l. of N.

Ans. Compass course N. 76° 46′ W; distance, 2784 miles.

Rules for Middle Latitude Sailing.

To find course: to log difference of longitude add log cos. mid-latitude, from this subtract log difference of latitude, the remainder is log tan. course.

To find departure: to log difference of longitude add log cos. mid-latitude, the sum, omitting 10, is the log of the departure.

To find distance: to log difference of latitude add log secant course, the sum, omitting 10, is log distance.

To find difference of longitude: add together log distance, log sine course, and log secant mid-latitude, omitting 10, the sum is log difference of longitude.

2. Required the compass course and distance from A to B (1866).

From A to B would be across the land, but it was set in 1866.

Lat. A 48° 15′, Lat. B 43° 18′ } N.; variation $1\frac{1}{2}$ pts. W.; deviation 5° 35′ E.; lon. A 12° 23′, lon. B 30° 15′ } E.

	Diff. lat.	Mid-lat.		Diff. lon.
A is in lat.	48° 15′ N.	48° 15′ N.	Longitude	12° 23′ E.
B is in lat.	43° 18′ N.	43° 18′ N.	Longitude	30° 15′ E.
	4° 57′	2)91° 33′		17° 52′
	60	$45° 46\frac{1}{2}'$ mid-lat.		60
Diff. lat.	297 miles S.		Diff. long.	1072′ E.

$$\text{Tan. Course} = \frac{\text{A B}}{\text{A C}} = \frac{\text{dep.}}{\text{diff. lat.}} = \frac{\text{diff. lon.} \times \text{Cos. mid-lat.}}{\text{diff. lat.}}$$

See last figure.

Log 1072 diff. lon.	3·030195
Log Cos. 45° 46½′ mid-lat.	9·843531
	12·873726
Log 297 diff. lat.	2·472756
Log tan. 68° 20′ course	10·400970

For distance.

$$\text{Cos. C} = \frac{\text{A C}}{\text{C B}} = \frac{\text{diff. lat.}}{\text{distance.}}$$

$\therefore$ dis. = diff. lat. × Sec. C.

Log 297 diff. lat. 2·472756

Log Sec. course 10·432731

Log 804·4 dist. 2·905487

For compass course.

True course S. 68° 20′ E is 68° 20′ l. of S.

Variation .... 16° 52′ 30″ r.

41° 47′ 30″ l.

Deviation .... 5° 35′ 0″ l.

47° 22′ 30″ l.

Ans. Compass course S. 47° 22′ 30″ E.; distance 804·4 miles.

3. Required the course and distance from A to B. Given:

Lat. A 45° 18′ N.; var. of compass $1\frac{1}{2}$ pts. E.; lon. A 36° 15″ E.
Lat. B 29° 27′ N.; deviation 2° 30′ E.; lon. B. 57° 18′ E. (1866).

This is also across the land and set in 1866.

Diff. of lat.	Mid-lat.	Diff. lon.
Lat. of A 45° 18′ N.	45° 18′ N.	Lon. 36° 15′ E.
Lat. of B 29° 27′ N.	19° 27′ N.	Lon. 57° 18′ E.
15° 51′	2)64° 45′	21° 3′ E.
60	32° $22\frac{1}{2}$ mid-lat.	60
Miles 951 S.		Diff. lon. 1263′ E.

$$\text{Tan. course} = \frac{\text{A B}}{\text{A C}} = \frac{\text{dep.}}{\text{diff. lat.}} = \frac{\text{diff. lon.} \times \text{Cos. mid-lat.}}{\text{diff. lat.}}$$

Log 1263 diff. lon. .... 3·101403
Log Cos. 32° $22'\frac{1}{2}$ mid-lat. ... 9·926632

3·028035

Log 951 diff. lat. .... 2·978181

Log tan. 4817′ Course .... 10·049854

For distance.

$$\text{Cos. Course} = \frac{\text{A C}}{\text{A B}} = \frac{\text{diff. lat.}}{\text{dist.}}$$

$\therefore$ Dis. = diff. lat. × Sec. course

Log 951 diff. lat. 2·978181

Log sec. 48° 17′ 10·176886

Log 1429 dist..... 3·155067

For compass.

True course is S. 48° 17′ E.

or 48° 17′ 0″ l. of S.

Variation... 16° 52′ 30″ l.

65° 9′ 30″ l.

Deviation... 2° 30′ 0″ l.

67° 39′ 30″ l. of S.

Ans. Compass course S. 67° 39′ 30″ E.; distance 1429 miles.

4. A master wishes to go from the Cape of Good Hope, latitude 34° 22′ S., longitude 18° 24′ E., to Berkley Sound, in the Falkland Isles, latitude 52° 21′ S., longitude 59° 18′ W., find the true course he must steer and the distance.

Cape of Good Hope,	lat. 34° 22′ S.	34° 22′	lon. 18° 24′ E.
Berkley Sound,	lat. 52° 21′ S.	52° 21′	lon. 59° 18′ W.
	17° 59′	2)86° 43′	77° 42′
	60	43° 21½′	60
	1079 S.		4662 W.

$$\text{Tan. C} = \frac{\text{diff. lon.} \times \text{cos. mid.-lat.}}{\text{diff. lat.}}$$

Log 4662 diff. lon.	3·668578
Log Cos. 43° 21′½ mid.-lat....	9·861579
	13·530151
Log 1079 diff. lat.	3·033021
Log tan. 72° 20′ course	10·497130

Dist. = diff. lat. × Sec. course.

Log. 1079 diff. lat.	3·033021
Log. sec. 72° 20′ course	10·517872
Log. 3555·4 distance..........	3·550893

Ans. Course S. 72° 20′ W.; distance 3555·4 miles.

5. Explain the principle and prove the rules of middle latitude sailing (1861).

6. Required the compass course and distance from A to B.

Lat. A 55° 40′, Lat. B 57° 50′ N.; var. 1½ E.; lon. A 29° 39′, lon. B 34° 15′ W. (1863).

Compass course N. 66° 13′ 30″ W.; distance 199·4 miles.

7. Required the compass course and distance from A to B.

Lat. A 9° 30′, Lat. B 14° 10′ N.; var. 1¾ pts. E.; lon. A 72° 15′, lon. B 65° 40′ E. (1863).

Compass course N. 73° 46′ 15″ W., distance 477·3 miles.

8. What is meant by middle latitude sailing? obtain the formulæ required for it.

Required the true course and distance from A to B, the latitude of A 57° 35′ N., and longitude 17° 16′ W., and latitude of B 55° 25′ N., longitude 20° 57′ W. (1863).

Ans. True course S. 43° 26′ W., distance 178·2 miles.

9. Find the compass course and distance between A and B.

Lat. A 33° 18′ S.; lon. A 72° 0′ W.; var. 16° E.

Lat. B 42° 3′ S.; lon. B 173° 30′ E.; dev. 9° 25′ E. (1870).

Ans. Course S. 59° 4′ W., distance 5461 miles.

10. Write down the formulæ for middle latitude sailing. Under what limitations would you apply this method? (see p. 93) (1865).

Required the compass course and distance from A to B.

Lat. of A 15° 20′, Lat. of B 19° 40′ S.; var. 2½ pts. W.; lon. A 4° 10′ E.; dev. 7° 50′ W.; lon. B 1° 20′ W. (1855).

Ans. Compass course S. 86° 23′ 30″ W., distance 408·1 miles.

11. What is the compass course and distance between A and B? Given:
Lat. A 35° 18′ S.; lon. A 171° 20′ W.; var. of compass $1\frac{1}{2}$ pts. W.
Lat. B 32° 14′ S.; lon. B 175° 18′ E.; dev. 10° E. (1871).
Ans. Compass course N. 67° 41′ 30″ W., distance 691·4 miles.

MERCATOR'S SAILING

UNDER the head of middle sailing it was pointed out that the rules there given should be used under certain restrictions, we now come to rules in navigation subject to no such restrictions. Mercator's sailing gives us formulæ for finding the course, distance, and difference of longitude under such conditions that we may take them as correct; not perfectly so, but yet so near the truth that there never need be any doubt as to the accuracy of the results obtained.

31. Mercator's Sailing is sailing a ship on the principles laid down by Gerard Mercator; or, perhaps more strictly, we may define it as finding a ship's course, distance, and longitude on the principles laid down by Mercator.

Mercator first taught how to construct charts in which the parallels, meridians, and rhumb lines are all represented by straight lines.

To an Englishman, Mr. Edw. Wright, is due the honour of first showing how these should be laid down with mathematical accuracy.

In Mercator's charts the meridians are all drawn parallel to each other. The consequence of this is, that their distances asunder are nowhere correct but at the equator; in all other parts of the world, as we proceed farther and farther from the equator, the error increases more and more. In all cases, except at the equator, as we said before, the meridians are too far apart; to compensate for this the degrees of latitude are made to increase in length from the equator to the poles.

It has been shown in parallel sailing that

Meridian distance = diff. lon. × Cos. latitude.
∴ diff. of lon. = meridian dis. × Sec. lat.

Hence it is evident that if we make

Mer. dis. = diff. of lon.

that we must increase the meridian distance in the ratio of the secant of the latitude. Now, when the meridians are drawn parallel to each other, the degrees or minutes of longitude are everywhere the same length, being increased in the ratio of the secant of the latitude, therefore the lengths of the degrees of latitude measured on the meridians must be increased by a proportionate length. Hence the first mile of latitude from the equator will be represented by $1' \times$ Sec. $1'$; the second by $1' \times$ Sec. $2'$; the third by $1' \times$ Sec. $3'$; the nth by $1' \times$ Sec. n'.

Therefore the distance of any parallel from the equator is given by taking the sum of all the natural secants, Sec. $1'$ + Sec. $2'$ + Sec. $3'$ + to n terms, and multiplying by $1'$. This method of finding the meridional parts is not strictly accurate, because the earth is not a perfect sphere, and the degrees of latitude measured on the meridians become a little longer as we approach the poles, but the error is of no consequence whatever in those latitudes in which it is practicable to sail a ship.

32. Meridional Difference of Latitude *is the true difference of latitude increased in the ratio of the secant of the latitude.*

We repeat a little. At the earth's equator a degree of longitude is equal in length to a degree of latitude; but as we recede from the equator and approach the poles, the degrees of longitude become less and less, while the degrees of latitude, supposing the earth to be a perfect sphere, remain the same. Now, in Mercator's projection of the earth on a plane, the degrees of latitude are severally increased in the same proportion as the degrees of longitude have been, by making them everywhere equal.

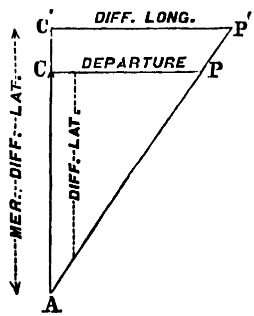
A formula will be investigated in the Advanced Work of this series, which shall give the value in miles of any latitude thus increased. The miles contained in the latitude so increased are called the meridional parts for that latitude. The annexed is the formula alluded to:—

$$\text{Log } m = \log(\log \text{Cot. } \tfrac{1}{2}\text{-Co-lat.} - 10) + 3{\cdot}8984895,$$

where m is the meridional parts required.

Suppose a ship to start from A and run to a place P. Now on a sphere the distance between A and P would be A P, the difference of latitude A C, and the departure C P.

We must now show how to represent a triangle similar to this on a Mercator's chart. Since the latitude and longitude on the chart are proportionally increased, the space required to represent the 180° of latitude and 360° of longitude on a plane would be greater than the surface required to represent the same extent of latitude and longitude on a sphere, by the difference between the areas of the requisite rectangular spaces on the chart, and the areas of two inscribed circles touching



each other and three sides of the rectangle. For this reason, the line representing the difference of latitude on a sphere is less than the corresponding line on Mercator. Also, the line representing the departure on the sphere becomes the difference of longitude on Mercator's charts; for since departure may be assumed as the sum of the infinitely small parts of parallels which form the sides of right-angled triangles, the other sides of which are infinitely small parts of the rhumb line and arcs of meridians;

and since in Mercator the degrees of longitude may be measured along any parallel, the sum of such arcs of the parallels on a sphere would in Mercator be represented by the sum of the differences of longitude taken at any distance from each other; that is, the departure on the sphere is represented by the difference of longitude on Mercator. That the distance on Mercator would be represented by a longer line than when represented on the sphere, is shown by reason of the difference of area required for the representation of the whole surface of the earth on a plane and on a sphere.

Let the foregoing figure represent a portion of the surface of the earth on Mercator's projection, where ACC′ is an arc of the meridian, and AP the distance sailed by a ship on a rhumb line. Let CP be a parallel of latitude passing over P. Then will angle CAP be the ship's course, AC the true difference of latitude made by the ship, and CP the departure.

Let AC′ represent the meridional parts corresponding to the true difference of latitude AC, and complete the figure by drawing C′P′ parallel to CP, meeting AP produced in P′. It can easily be proved that if C′P′ represent the difference of longitude AP and PP′ form one straight line, when the former is joined to P′

AC′ is the meridional difference of latitude.
AC ,, ,, true ,, ,, ,,
CP ,, ,, departure.
C′P′ ,, ,, difference of longitude.

$$\text{Tan Course} = \frac{C'P'}{AC'} = \frac{\text{difference of longitude.}}{\textit{Meridional diff. of lat.}} \quad \text{I.}$$

$$\therefore \text{ diff. lon.} = \text{mer. diff. lat.} \times \text{Tan. course.} \quad \text{II.}$$

When the course is found we use the true difference of latitude to find distance.

$$\text{Cos. Course} = \frac{\text{diff. lat.}}{\text{distance.}}$$

$$\therefore \text{ dist.} = \text{diff. lat.} \times \text{Secant course.}$$

These are all the rules necessary for Mercator's sailing.

1. March 12, at 5.20 p.m., I leave St Ann's Head in lat. 51°41′ N.,

lon. 5° 9′ W. for Land's End, in lat. 50° 4′ N., lon. 5° 42′ W., how must I steer by compass? allowing 23° westerly variation, 3° W. for deviation, and ¼ point leeway, the wind being E.S.E. What distance shall I run, and when shall I arrive, supposing that my rate of sailing is 10 knots an hour (1869)?

	Diff. lat.	M. P.	Diff. lon.
St Ann's Head,....Lat.	51° 41′ N.	3635	Lon. 5° 9′ W.
Land's End,........Lat.	50° 4′ N.	3481	Lon. 5° 42′ W.
True diff. of lat.	1° 37′	154	diff. lon. 33′ W.
	60		
	97 S.		

$$\text{Tan. C.} = \frac{\text{diff. lon.}}{\text{mer. diff. lat.}}$$

Log 33, diff. lon ....1·518514
Log 154, mer. diff. lat.........2·187521
Log Tan. 12° 5′ Course = 9·330993

Dist. = true diff. lat. × Sec. Course.

Log 97, diff. lat............ 1·986772
Log Sec. 12° 5′ Course....10·009730
Log 99·19 miles............ 1·996638

True Course S. 12° 5′ W.; distance 99 miles.

Compass Course.

True Course...	12° 5′ 0″ r.	of S.
Variation	23° 0′ 0″ r.	
	35° 5′ 0″ r.	of S.
Deviation......	3° 0′ 0″ r.	of S.
	38° 5′ 0″ r.	of S.
Leeway.........	2° 48′ 45″ l.	
	35° 16′ 15″ r.	of S.

Compass Course S. 35° 16′ 15″ W.

$$\text{Time of sailing} = \frac{99{\cdot}19}{10}$$
$$= 9{\cdot}9 \text{ hours.}$$

Started on March 12 at 5h. 20m.
Time going................9h. 55m.
12 at...15h. 15m.

Or ¼ past 3 in the morning.

We will explain fully how this problem is worked.

(1) Put down the latitude and longitude as above, and find the differences of latitude and longitude, and take out the meridional parts from the table-book, putting them opposite the latitudes to which they correspond.

(*a*) To find the difference of latitude when both are N., or both S., subtract for the difference; but if one be north and the other south, add for the difference.

Note.—If you add the latitudes together add the meridional parts together; if you subtract one pair subtract the other.

(2) *Find the course.*—From logarithm difference of longitude subtract logarithm of meridional difference of latitude, mentally adding 10 to the index of the first logarithm; the remainder is the tangent of the course which must be taken out from the tables.

(3) *To find distance.*—To the logarithm of the true difference of latitude add log secant course (omitting 10 in the index), the sum gives log distance to be found in the tables.

(4) Find the compass course as before, remembering to allow leeway *towards* the wind.

2. Find the compass course and distance from A to B. Given:

Lat. A 30° 18′ S.; var. 1 pt. E.; lon. A 17° 18′ W.
,, B 21° 33′ N.; dev. 6° 15′ E.; ,, B 3° 17′ E. (1868).

	Diff. lat.	M. P.		Diff. lon.
Lat.	A 30° 18′ S.	1909	Lon.	A 17° 18′ W.
,,	B 21° 33′ N.	1325	,,	B 3° 17′ E.
	51° 51′	3234		20° 35′
	60			60
True diff. lat.	3111 N.		Diff. lon.	1235 E.

$$\text{Tan. C.} = \frac{\text{diff. lon.}}{\text{M. D. of lat.}} \qquad \text{Dis.} = \text{true diff. lat.} \times \text{Sec. C.}$$

Log. 1235 diff. lon.	3·091667	Log. 3111 diff. lat.	3·492900
Log. 3234 M. D. of lat.	3·509740	,, Sec. 20° 54′ course	10·029558
Log. Tan. 20° 54′ course	9·581927	Log. 3330 dist.	3·522458

True Course, N. 20° 54′ E.; distance, 3330 miles.

Compass Course.	
True Course,	20° 54′ 0″ r. of N.
Variation,....	11° 15′ 0″ l.
	9° 39′ 0″ r. of N.
Deviation, ...	6° 15′ 0″ l.
Compass Course,	3° 24′ 0″ r. of N. or N. 3° 24′ E.

Observations on this question.—It will perhaps be noted that this question would leave the vessel in the S. of the Sahara desert! So it must have therefore been simply given as an illustration of the rules.

One latitude being N. and the other S., they are added together to find the difference of latitude, hence the meridional parts are added.

The longitudes being one east and the other west, are also added to find the difference.

The course is marked N.E., because the ship goes from S. to N. latitude and from W. to E. longitude.

Course, distance, and compass course are found as in the previous question.

3. A ship sails from latitude 37° 18′ N., longitude 49° 27′ W., in a direction N.N.W. 470 miles; what are her latitude and longitude in? and what course must she now steer for New York, lat. 40° 42′ N., longitude 73° 59′ W. (1869)?

Here we must first find difference of latitude by plane sailing, and then latitude in; then difference of longitude and longitude in; next course to New York.

Diff. lat. = dis. × Cos. course.		diff. lon. = mer. diff. lat. × Tan. C.	
Log 470 dis.	2·672098	Log 576 mer. diff. lat.	2·760422
Cos. 2 pts. course,	9·965615	Log Tan. 2 pts. course	9·617224
Log. 434·2 diff. lat.	2·637713	Log 238·5 diff. lon, ...	2·377646

Lat. in.		M. P.	Lon. in.	
Lat. from......	37° 18′ 0″ N.	2415	Lon. from	49° 27′ 0″ W.
Diff. lat. (434·2)	7° 14′ 2″ N.		Diff. lon. (238·5)	3° 58′ 30″ W.
Lat. in..........	44° 32′ 2″ N.	2991	Lon. in	53° 25′ 30″ W.
		576		

We have now to find course from latitude 44° 32′ 2″ N., longitude 53° 25′ 30″ W., to New York, lat. 40° 42′ N., longitude 73° 59′ W.

	Diff. lat.	M. P.		Diff. lon.
Lat. from	44° 32′ 2″ N.	2991	Lon. from	53° 25′ 30″ W.
Lat. N. Y.	40° 42′ 0″ N.	2678	Lon. N. Y.	73° 59′ 0″ W.
	3° 50′ 2″	313		20° 33′ 30″
	60			60
True diff. lat.	230·2 S.		Diff. lon.	1233·5 W.

$$\text{Tan. C.} = \frac{\text{diff. lon.}}{\text{mer. diff. lat.}}$$

Distance.
Dis. = diff. lat. Sec. course.

Log. 1233·5 diff. long.	3·090980	Log. 230·2 diff. lat.	2·362105
Log. 313 M. D. lat. ...	2·495544	Log. Sec. 75° 45′ C.	10·608794
Log. Tan. 75° 45′ C....	10·595436	Log. 935·1 dist.	2·970899

True course to New York, S. 75° 45′ W., distance 935 miles.

The next is given as a simpler illustration:—

4. Find the course and distance from the Cape of Good Hope, latitude 34° 22′ S., longitude 18° 24′ E., to the Falkland Isles, latitude 52° 21′ S., longitude 59° 18′ W., by Mercator's sailing.

	Diff. lat.	M. P.		Diff. lon.
Lat. of Cape of Good Hope,	34° 22′ S.	2198	Lon.	18° 24′ E.
,, Falkland Isles, ...	52° 21′ S.	3699	,,	59° 18′ W.
	17° 59′	1501		77° 42′
	60			60
	1079 S.			4662 W.

$$\text{Tan. C.} = \frac{\text{diff. long.}}{\text{M. D. of lat.}}$$

Dis. = diff. lat. × Sec. C.

Log. 4662...........	3·668572	Log. 1079...........	3·033021
Log. 1501...........	3·176381	Log. Sec. 72° 9′...	10·513533
Log. Tan. 72° 9′ ..	10·492191	Log. 3520..........	3·546554

Ans True course, S. 72° 9′ W.; distance, 3520 miles.

By middle latitude sailing the answers were—

True course, S. 72° 20′ W.; distance, 3588 miles.

5. Find the course and distance by Mercator's sailing from C. Farewell, latitude 59° 49′ N., longitude 43° 54′ W., to C. Wrath, latitude 58° 38′ N., longitude 4° 57′ W.

	Diff. lat.			Diff. lon.
Cape Farewell, lat.	59° 49′ N.	4505	lon.	43° 54′ W.
Cape Wrath, ,,	58° 38′ N.	4367	,,	4° 57′ W.
	1° 11′	138		38° 57′ E.
	60			60
	71° S.		diff. lon.	2337 E.

Tan. C. = $\dfrac{\text{diff. lon.}}{\text{M D of lat.}}$	dist. = diff. lat. × Sec. course.
Log 2337............... 3·368659	Log 71............... 1·851258
Log 138 .... 2·139879	Log sec. 86° 37′...11·229030
Log tan. 86°37′ ......11·228780	Log 120·3.......... 3·080288

Ans. Course S. 86° 37′ E.; distance, 1203.

If the variation be 43° W., and deviation 9° E., and leeway 2 pts. with wind from N., find the compass course.

True course,......................	86° 37′ 0 l. of S.
Variation,........................	43° 0′ 0 r.
	43° 37′ 0 l. of S.
Deviation, ...	9° 0′ 0 l.
	52° 37′ 0 l. of S.
Leeway, ...	22° 30′ 0
Compass course,................	75° 7′ 0 l. of S. or S. 75° 7′ E.

These answers will differ a little, according to the tables used.

6. Find the course and distance by Mercator's sailing from Start Point, latitude 50° 13′ N., longitude 3° 38′ W., to Ushant, latitude 48° 28′ N., longitude 5° 3′ W. ?

Ans. Course S. 27° 58′ W., distance 118·8 miles.

7. In what direction must I place my ship's head, by compass, to reach Kinsale light, starting from the Longship's light, the variation being 2 pts. W., and deviation ¾ pt. W.?

Latitude of the Longship's light, 50° 4′ N., lon. 5° 44′ W.
,, Kinsale ,, 51° 37′ N., lon. 8° 27′ W.

Ans. Course N. 17° 0′ 45″ W.; distance 138·8 miles.

8. What is the course and distance by Mercator's sailing from Heligoland, latitude 54° 12′ N., longitude 7° 53′ E., to the Inch Cape light, latitude 56° 27′ N., longitude 2° 23′ W.

Ans. Course N. 68° 57′ W.; distance 375·8 miles.

9. Find the compass course and distance from Plymouth (Penlee), latitude 50° 19 N., longitude 4° 11′ W., to Jersey, latitude 49° 15′ N., longitude 2° 2′ W., variation 21° W., deviation 7° E.

Ans. S. 38° 29′ E.; distance 105 miles.

10. What is the true course and distance by Mercator's sailing from Cape Verde, latitude 14° 45′ N., longitude 17° 32′ W., to Monte Video, latitude 34° 53′ S., longitude 56° 16′ W.

Ans. Course S. 36° 51′ W.; distance 3684 miles.

11. What is the course and distance by a compass with 17° E. variation and ¾ pts. E. deviation, from Cape Mendocino in latitude 40° 29′ N., longitude 124° 29′ W., to the Solomon Isles, latitude 7° 15′ S., longitude 157° 45′ E.

Ans. Course S. 30° 58′ W.; distance 5177 miles.

12. Find the course and distance from Valparaiso, latitude 33° 2′ S., longitude 71° 40′ W., to Foveaux Straits, latitude 47° 16′ S., longitude 167° 15′ E. *Ans.* C. S. 81° 14′ W.; dist. 5603 miles.

13. By Mercator's sailing find the true course and distance from Cape Horn, latitude 55° 59′ S., longitude 67° 12′ W., to the Cape of Good Hope, latitude 34° 22′ S., longitude 18° 24′ E.

Ans. Course N. 70° E.; distance 3792 miles.

14. A vessel sails from Bourbon, 430 miles N. by E.: find the course and distance thence to Point de Galle, variation of compass 5° W., deviation 2 pts. W. Bourbon, latitude 20° 52′ S., longitude 35° 27 E.; Point de Galle, latitude 6° 1′ N., longitude 80° 18′ E. *Ans.* Course S. 87° 7′ E.; distance 2859 miles.

33. Mercator's Charts.—We have now to show how Mercator's charts are practically constructed, and why they are used by mariners in preference to every other kind of map, and then point out a few simple rules to guide the student in using them.

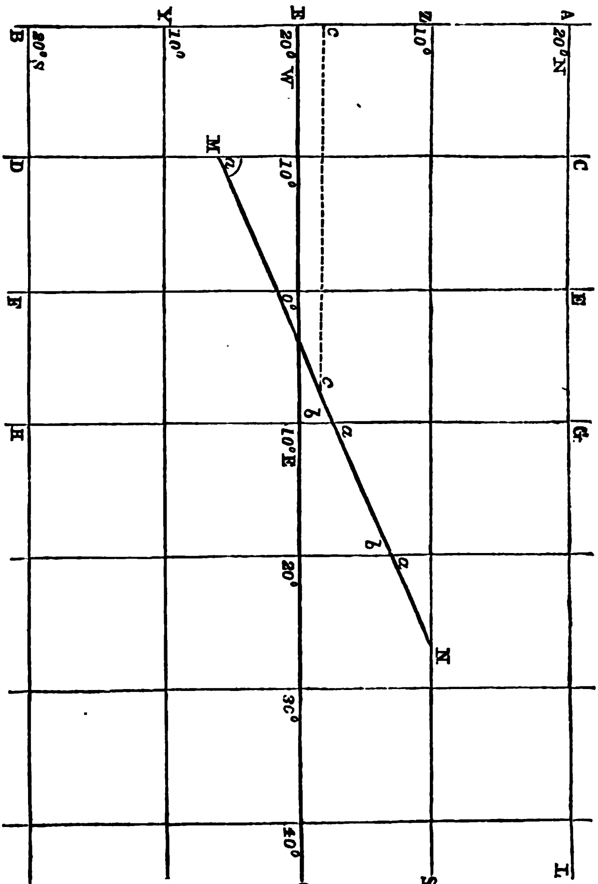
The best way to construct a chart is as follows:—First draw a line across the middle of the paper, from right to left, to represent the equator, E Q. Second, draw a few vertical lines at *equal* distances apart, and cutting the equator at right angles at A B, C D, E F, G H, etc., let these lines represent the meridians everywhere the same distance apart. Third, suppose the meridians we have drawn are 10° apart, or 600 miles at the equator (the student may suppose them any distance apart he pleases, 1°, 2°, 3°, etc.)

Then from	0° to 10°	is 600 miles.
,,	10° to 20°	,,
,,	20° to 30°	,,
,,	etc., etc.	,,

Fourth, go to the table of meridional parts, and as we have supposed the meridians are 10° asunder, we will suppose the parallels are also 10° apart, and take out the meridional parts for—

10° = 603
20° = 1225   1225 − 603 = 622
30° = 1888   1888 − 1225 = 663
40° = 2623   2623 − 1888 = 735
etc., etc., as many as are required.

Now, take in the compasses 603 parts, remembering that from 0° to 10° is 600, and measure them up and down from the point E and Q, from E to Z and Y, and Q to S


A
20° N
C
E
G
L
Z
10°
S
c
c
E
20° W
10°
0°
10° E
20°
30°
40°
Q
M
N
a
b
Y
10°
B
20° S
D
F
H
O

and R; through Z and S and Y and R, draw the lines Z S and Y R; we have now the first two parallels, one 10° N. of the equator, the other 10° S. of the equator.

For the next two parallels, either measure up and down from E and Q 1225 parts (of which 0° to 10° are 600), or measure 622 up and down from the two lines Z S and Y R; through the points thus obtained, draw the lines A L and B O, which are the parallels of 20° S. of the equator. The next pair of parallels of 30° must be drawn at 1888 parts from the equator, or 663 parts from the lines A L and B O; unfortunately the page will not admit of showing these, or it would be seen how the distances apart of the parallels gradually increase. The student must not rest until he can readily draw a Mercator's chart.

The great advantage of Mercator's chart is this, that if you draw a line from any one place to another, the angle at which that line cuts the meridian is the course from the one place to the other.

Let M be one place on the earth's surface and N another. Join them by the straight line M N; then the angle *a* is the course from M to N, and *b* the course from N to M.

The master of the vessel generally has a large parallel ruler, which he places on the two places, and then moves the ruler up to the centre of the compass, of which there are generally more than one marked on the chart. As soon as he has his parallel ruler on the compass, he sees in a moment what the course is, as the ruler is pointing in that direction.

Another advantage is this: that you can tell with a pair of compasses in a moment what is the distance between two places. Suppose *c* is the middle point of M N. Carry point *c* to the side of the chart; then measure half the length of M N up and down from this point, when the number of degrees lying on the meridian between the two points thus found will give the distance between the two places when brought into nautical miles. The latitude of a place is found by simply bringing the

eye in a line from the place to the side of the chart, and the longitude by bringing the eye straight down to the bottom or up to the top of the chart.

15. Explain the principles of Mercator's chart popularly, as to an elementary navigation class (1861). Describe a Mercator's chart (1863).

16. Required the compass course and distance from A to B.

$$\left.\begin{array}{l}\text{Lat. A } 55^\circ\ 40'\\ \text{Lat. B } 57^\circ\ 50'\end{array}\right\}\text{N.; var. } 1\tfrac{1}{2}\text{ E.; }\left.\begin{array}{l}\text{lon. A } 29^\circ\ 30'\\ \text{lon. B } 32^\circ\ 15'\end{array}\right\}\text{W.}\qquad(1863).$$

Compass course, N. 51° 49′ 30″ W.; distance, 158·6 miles.

17. Explain how to draw a Mercator's chart, and show how to find the latitude and longitude of a place on the chart (1864).

18. Write down the formulæ used in Mercator's sailing. Find the true course and distance from A to B (1864).

Lat. A 27° 18′ N.; lon. A 3° 15′ W.
Lat. B 15° 16′ S.; lon. B 27° 3′ W.

Ans. S. 28° 38′ W.; distance, 2910 miles.

19. Required the compass course and distance from A to B.
Lat. of A 37° 27′ N.; var. 2 pts. E.; lon. A 54° 19′ W.
Lat. of B 14° 17′ S.; dev. 1° 50′ E.; lon. B 30° 15′ W. (1865).

Ans. Compass course, S. 48° 8′ E.; distance, 3392 miles.

20. Show how to calculate approximately a table of proportional parts.

Given the meridional parts for 28° = 1741′.
Calculate the meridional parts for 28° 15′. (1865).

The first part of the question is answered in any book on trigonometry; but if we show how this problem is done, that will answer the question sufficiently.

The meridional parts for 28° (or 28 × 60 = 1680′) being 1741; what is the meridional parts for 28° 15′ or 1695′.

$$\begin{array}{rr}
\text{As} & 1680 : 1695 : : 1741 \\
\text{or, as} & 112 : 113 : : 1741 \\
 & 113 \\
\hline
 & 5223 \\
 & 19151 \\
\hline
 & 112)196733(1756,\ \textit{Ans.} \\
 & 112 \\
\hline
 & 847 \\
 & 784 \\
\hline
 & 633 \\
 & 560 \\
\hline
 & 733 \\
 & 672 \\
\hline
 & 61
\end{array}$$

This is not strictly accurate, but near enough for the purpose required, and is what the examiner asks for.

21. Explain how a Mercator's chart may be constructed, and show how to find the course and distance from two points on it (1865).

Find the compass course and distance between A and B.

Lat. A 33° 18′ S.; lon. A 72° 0′ W.; var. 16° 0′ E.
Lat. B 42° 3′ S.; lon. B 173° 30′ E.; dev. 9° 25′ E. (1870).

Ans. Compass course S. 59° 5′ W.; distance 5461 miles.

22. What is meant by Mercator's projection and meridional difference of latitude. Given meridional parts for lat. 35° = 2233; find by calculation meridional parts for 35° 18′ (1860).

Ans. 2251.

23. A ship in lat. 13° 5′ N., lon. 37° 18′ W., is to make a point of land in lat. 33° 10′ N., lon. 54° 33′ W.; find the compass course she must steer and the distance. Given variation $1\frac{1}{2}$ points W., deviation 8° 12′ W. (1867).

Ans. Compass course, N. 21° 21′ 30″ W.; distance 1534 miles.

24. What do you mean by meridional parts? What is the mer. diff. lat. of two places whose latitudes are 12° 18′ N. and 8° 12′ S. respectively (1867)? *Ans.* 1238.

25. What are the compass course and distance between New York and Cape Palmas? Given:

New York, ... lat. 40° 40′ N.; lon. 74° 0′ W.; var. $1\frac{1}{4}$ W.
Cape Palmas, lat. 3° 58′ N.; lon. 7° 22′ W.; dev. 7° 50′ W.
(1871). *Ans.* Comp. course S. 34° 3′ 30″ E.; dist. 4246 miles.

26. Find the course and distance from A to B. Given:

Lat. A 53° 18′ S.; lon. A 76° 14′ E.; var. $1\frac{1}{4}$ E.
Lat. B 56° 25′ S.; lon. B 78° 13′ E.; dev. 8° E. (1872).

Ans. Course S. 42° 13′ 45″ E.; distance, 199·2 miles.

27. Define the following terms in navigation: Course, departure, meridional difference of latitude, difference of longitude (1864).

$$\text{Prove Tan. course} = \frac{\text{diff. long.}}{\text{mer. diff. lat.}} \quad (1864).$$

GREAT CIRCLE SAILING.

34. A MERE elementary explanation of **Great Circle Sailing** will be given, that being all that is required in this stage of the subject.

It is generally advantageous for a ship to reach her port by the shortest route she can, although in some cases ships go hundreds of miles out of their course to meet a favourable current of wind or water. The distance, or rhumb line, as shown on a Mercator's chart, though always a sure way of reaching a ship's destination, is not always the shortest. The *least distance* between any two places on the earth's surface is the arc of a great circle lying between them; consequently all rhumb lines described in sailing from one place to another are longer than the arc of the great circle passing through the two places, except, of course, in the two cases where the rhumb line happens to coincide with the great circle, viz., when she sails on the equator, and when she goes due north or south on a meridian.

A *great circle* has been previously defined as one that divides the sphere into two equal parts.

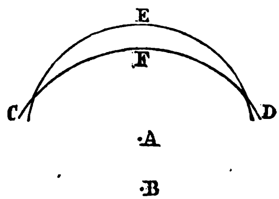
That the course of a ship may be known, she must continue in one direction for some time, and while it continues in this one direction its track is a rhumb line. It is impossible to keep the ship exactly upon any assigned line which is not a rhumb line, so that a ship cannot be made accurately to describe a great circle upon the surface of the globe, except, as was hinted before, when she sails due E. or W. on the equator, or N. and S. on a meridian. But although the ship cannot be kept exactly upon any given great circle, she may be continually brought near it, and kept near it, so as sufficiently to answer the end and aim of great circle sailing. In fact, by continually paying attention to the course, and keeping as near as possible to the great circle, the course of the ship may be said to describe part of a polygon, with a large number of sides within the arc of the great circle.

It has been shown that the sailings depend upon the solution of plane triangles, but great circle sailing depends upon the solution of right-angled and oblique-angled spherical triangles, chiefly the latter; and were it not that it is made subservient to nautical purpose, the solu-

tion of such problems would belong to Spherical Trigonometry, and not to Navigation.

On a large globe it is very easy to mark out the great circle between two places, and to find their distance asunder by so moving the globe as to bring the two places to the wooden horizon; when in this position we can observe how the great circle track lies; we may also notice that the great circle does not meet the meridians at the same angle; it is this that renders it necessary to continually alter the course in great circle sailing, and also makes it impossible for a ship to remain for any continuous length of time on the great circle.

Mathematically, it is a very difficult problem to show that the arc of a great circle is the shortest route between two places; but, mechanically, it is easily done by stretching a fine string from one place to the other when they are brought to the wooden horizon. If we turn up the places and make trials with the length of string thus obtained, by stretching it in various positions between the two places, we shall find it is the shortest line.



Again, by examining this simple figure we may see that the larger the radius of the circle the shorter the curve lying between the two points C and D. Hence as a great circle is the largest that can be drawn on a sphere, its arc must be the shortest route between any two places.

Let A be the centre of the arc C E D passing through C and D. Let B be the centre of the arc C F D passing through C and D.

It is at once obvious that the arc C F D of the larger circle is the shorter distance between C and D, and the larger the radius B D, the nearer C D approaches to a straight line, the shortest distance between two places.

Define a great circle and small circle of a sphere, giving examples of each (1870).

CURRENT AND OBLIQUE SAILING.

35. A Current is a body of water (or air) flowing steadily in a certain direction.

The *set* of a current is the direction in which it is moving.

The *drift* of a current is the rate at which it moves. A ship may sail with the current, or against it, or obliquely to it. When a ship sails with a current, her motion is evidently increased by the whole drift of the current, and her run is equal to the sum of her own proper motion and that due to the drift of the current; but when she sails against the current her motion is diminished by its drift, and the run of the ship in the given time is equal to the difference between her own proper motion and the current's drift. When the ship sails obliquely to the current, the current will retard or accelerate the motion of the vessel according to the direction of the current in proportion to the angle at which the direction of the ship's head lies across it. The ship will sail along the diagonal of a parallelogram, of which the force or rate of the current forms one side, and the proper velocity of the ship the other.

A simple practical method of finding the set and drift of a current is to get into a boat, and, having rowed a short way from the ship, let fall a small anchor or heavy weight, this will keep the boat still; next throw overboard the log and log-line, the rate at which the line runs out will be the *drift* of the current, and the direction (taken by a small boat compass) will be its set.

36. Oblique Sailing.—It is sometimes found advantageous by those who possess the requisite knowledge, to solve a few of the problems in Navigation by the ordinary rules of Trigonometry. This is generally termed oblique sailing. A vessel in the open ocean out of sight of land can seldom or never make use of the rules of oblique sailing; but in coasting, in approaching the land, islands, shoals, etc., oblique sailing is of assistance in a

variety of ways. They are really trigonometrical problems, and that of itself is a sufficient reason for not entering more fully into the matter here.

1. My ship sails for 12 hours on a S. by W. course 7 miles an hour in a current setting E.N.E. 3 miles an hour, required her true course and destination.

Courses.	Dist.	Diff. lat.		Departure.	
		N.	S.	E.	W.
S. by W.	84		82·4		16·4
E.N.E.	36	13·8		33·3	
		13·8	82·4	33·3	
			13·8	16·4	
			68·6	16.9	

Ans. Course, S. 14° 16′ E.; distance 70·8 miles.

Here, it will be noticed, that the problem consists of two courses and distances, so a small traverse is made, and the answer obtained in the usual way.

2. A ship sails N.N.E. for 5 hours 4 miles an hour, while a currents sets her N.W. one mile an hour, what is the true course and distance she made?

This question, although it may be solved by trigonometry, is a simple problem. We have simply two courses and distances to resolve into one course and distance.

Courses.	Dist.	Diff. lat.		Departure.	
		N.	S.	E.	W.
N.N.E.	20	18·5		7·7	
N.W.	5	3·5			3·5
		22		7·7	3·5
				3·5	
				4·2	

∴ Course is N. 11° E.; 22 miles.

3. A ship steams 10 knots an hour, and her compass course is S. by W., what is her true course and distance in $4\frac{1}{2}$ hours, a current drifting her S.W. $\frac{3}{4}$-W. $2\frac{1}{4}$ knots an hour? Variation $2\frac{1}{2}$ points E., deviation one first course 4° 10′ E., and on current course 5° W.

Ship's Course.		Current Course.	
Compass, ..	11° 15′ 0″ r. of S.	S.W. $\frac{3}{4}$-W. =	53° 26′ 15″ r. of S.
Variation, .	28° 7′ 30″ r.	Variation,	28° 7′ 30″ r.
	39° 22′ 30″ r.		81° 33′ 45″ r. of S.
Deviation, .	4° 10′ 0″ r.	Deviation,	5° 0′ 0″ l.
	43° 32′ 20″ *r* of S.		76° 33′ 45″ r. of S.
	or S. 44° W.		or S. 77° W.

Courses.	Dist.	Diff. lat. N.	Diff. lat. S.	Departure. E.	Departure. W.
S. 44° W. . . .	45		32·4		31·3
S. 77° W. . . .	10·1		2·3		9·8
			34·7		41·1

Ans. Course S. 50° W.; distance 54 miles.

4. In sailing down channel I observed the Start bearing due N., the ship then sailed S.E. for 12 miles, I then observed that the Start bore N.W. by N.: find the distance from the Start at each observation.

Let S be the Start Point; B the position of the ship at the first observation. Let the ship sail from B to A 12 miles; then the Start bears N.W. by N., or lies in the direction of the line AS.

$\angle$BAD = ABE = 4 pts. ∵ ship sails S.E.
$\angle$EAS = 3 ,, ∵ the Start bears N.W. by N.
∴ $\angle$BAS is *one* point.
and $\angle$ABS is *evidently* 12 pts
∴ $\angle$BSA is *three* points.

Since

$$\frac{\text{Sin. SAB}}{\text{Sin. BSA}} = \frac{\text{BS}}{\text{AB}} = \frac{\text{BS}}{12} = \frac{\text{Sin. 1 pt.}}{\text{Sin. 3 pts.}}$$

$$\therefore \text{BS} = \frac{12 \times \text{Sin. 1 pt.}}{\text{Sin. 3 pts.}}$$

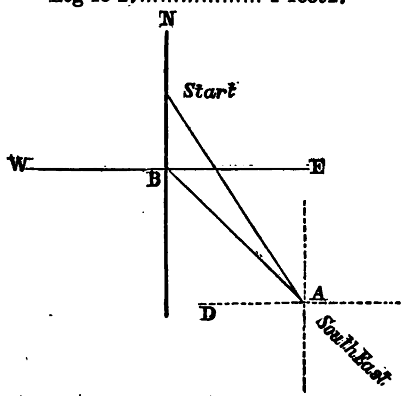
Log 12...........	1·079181
Log sin. 1 pt. ..	9·290236
	10·369417
Log sin. 3 pts.	9·744739
Log 4·213........	0·624678

Again

$$\frac{\text{Sin. ABS}}{\text{Sin. ASB}}=\frac{\text{AS}}{\text{AB}}=\frac{\text{AS}}{12}=\frac{\text{Sin. 12 pts.}}{\text{Sin. 3 pts.}}$$

$$\therefore \text{ AS}=\frac{12\times\text{Sin. 12 pts.}}{\text{Sin. 3 pts.}}$$

Log 12.....................	1·079181
Log sin. 12 pts. (4 pts.)	9·849485
	10·928666
Log sin. 3 pts............	9·744739
Log 15·27.................	1·183927



At the first observation the ship is 4·213 miles from the Start, at the second 15·27 miles.

5. From my ship a cape bore S.S.E. 4 miles away, I then sailed on a certain course and distance between S. and E. till the same cape bore W.S.W. 3 miles away: find my course and distance. *Ans.* Distance 5 miles, course S. 59° 22′ E.

6. Plymouth breakwater light bore from a yacht S.S.W. 3 miles distant, it then sailed 5 miles S.: find the bearing and distance of the light at the second observation.

Ans. W.N.W. distance 4 miles.

7. A point bears N.W. by W., I sail directly to the point, finding the distance 4 miles, the vessel is then put on a N.E. by N. course for 3 miles: what is now the distance from, and course to, the starting point? *Ans.* S. 19° 23′ E.; distance 5 miles.

8. Coasting along the shore of the Isle of Wight I saw St Catherine's point bearing from me N.E. by N., then I stood away N.W. 20 miles, and observed the point bearing from me E.N.E.: required the distance of the ship from the cape at each station. *Ans.* 33·26 and 35·2.

9. At noon a headland bore N.W. by W., then we sailed N.N.E. 5 miles an hour, and anchored at 9 in the evening on a bank 54 miles from the headland: required the distance of the headland from the ship at noon, and its bearing from the bank.

Ans. 39·9 miles; S. 68° 56′ W., about W.S.W. ¼-W.

10. Being out at sea in sight of land I observed two headlands, one bearing N. by W., the other N.W., taking up the chart I find they are 12 miles apart, and bear E.N.E. from each other: find the distances of the ship from the two headlands.

Ans. 21·18 miles from one, and 15·27 miles from the other.

11. A ship steams 11 knots an hour, and her apparent course is W. by S.: what is her true course in 4¾ hours, suppose a current drifting N. N. E. 2 knots an hour (1863)?

Ans. N. 88½° W.

12. In sailing down the channel I observe the Eddystone Lighthouse due N., after sailing S.W. for 8 miles I observe it again, and find its bearing N.N.E.:* what was its distance from me at each of the observations (1865)?

Ans. 8 miles, and 14·78 miles.

13. How is the effect of a current allowed for? A ship sailing 4 hours on a corrected course S.E. ½-E. over an apparent distance of 75 miles is set during the time by a current E. by N. by the compass 4 miles an hour, deviation 8° 15′ E.: what are the true course and distance (1867)? *Ans.* S. 57° E., 87 miles.

* I have corrected a misprint here, and written N.N.E. for E.N.E.

EXAMINATION PAPER ANSWERED TO SHOW THE STUDENT HOW TO SET DOWN HIS WORK.

General Instructions.

You are only permitted to answer questions from the Elementary Paper or from the Advanced Paper, but not from both. If the rules are not attended to, the paper will be cancelled.

In all cases the number of the question must be placed before the answer on the worked paper.

The value attached to each question is shown in brackets after the question. But a full and correct answer to an easy question will in all cases secure a larger number of marks than an incomplete or inexact answer to a more difficult one.

Three hours are allowed for this paper.

FIRST STAGE OR ELEMENTARY EXAMINATION.

Instructions.

You are only permitted to attempt eight questions, viz., four out of each of the sections into which the paper is divided.

Section I.

1. Define *rhumb line.* What is the name given to the angle which a rhumb line makes with a meridian?

A ship is sailing N.E.$\frac{3}{4}$-E., and the direction of the head is changed by 118° through the North; what is the new course of the ship in points to the nearest quarter? ($12\frac{1}{2}$).

2. What are the several corrections to be applied to the apparent to obtain the true course?

Correct the following courses:—

	Apparent Course.	Variation of the compass.	Variation.	Direction of wind.	Leeway.
(1)	N.W.	1¾ pts. E.	10° W.	N.N.E.	2½ pts.
(2)	S.W.½-W.	2 pts. W.	4½° W.	S.S.E.	1¾ pts.
(3)	N.	1¼ pts. E.	11° E.	S.byE.	0 pts.
(4)	S.byE.	1½ pts. E.	3° E.	W.S.W.	1¾ pts. (12½).

3. Explain the method of swinging a ship for the purpose of making tables of deviation. The standard compass on board marks S.W.½-W.; and that on shore N.E.byE.½-E. What is the deviation? (12½).

4. Prove that the arc of a parallel of latitude is equal to the corresponding arc of the equator multiplied by the cosine of the latitude. (12½).

5. Define the terms departure, nautical distance, true diff. lat. and diff. lon., and shew that departure = true diff. lat. × tan. course. (12½).

6. Describe the log, and explain its use. Supposing the nautical mile to be 6080 feet, and the glass to run out in 30 seconds, what is the corresponding length of the knot? (12½).

SECTION II.

7. In sailing on a parallel of latitude I find the distance actually made good is 38 nautical miles, while I have changed my longitude by one degree, on what parallel am I sailing? (10).

8. A ship sails from lat. 38° 4′ N., S.E.byS., till her departure is 50 miles; required the distance she has sailed, and her latitude. Construct a figure. (10).

9. Find the compass course and distance from A to B. Given:

Lat. A 36° 18′ N.; lon. A 45° 18′ E.; var. of compass ¾ pt. E.
Lat. B 13° 27′ N.; lon. B 45° 18′ E.; dev. 4° E. (12½).

10. A ship is in lat. 45° 18′ S., lon. 44° 25′ E., and sails in a W.S.W. direction until she is in latitude 47° 14′ S., required the distance run, and the departure. (10).

11. A ship is in lat 38° 44′ N., lon. 18° 33′ W., and sails by compass E.N.E. 70 miles; required the latitude and longitude in, given variation of compass ¾ pt. W., deviation 8° E., leeway 1 pt., direction of wind E.S.E. (12½).

12. A ship sails from lat. 51° 25′ N., lon. 8° 12′ W., S.S.E. 30, E.byS. 18, S.W.byW. 36, W. ¾ N. 14, and S.E.byE. ¼ E. 46 miles; required the equivalent course and distance, and the latitude and longitude of the place arrived at. (15).

ANSWERS TO FOREGOING PAPER.

1. A rhumb line is the track of a ship, or see p. 102. The angle which it makes with the meridian is called the course.

If the ship is sailing N.E. $\frac{3}{4}$-E., and the direction of her head is changed by 118° through N., the new course will be found thus:

N.E. $\frac{3}{4}$-E. is $4\frac{3}{4}$ or 53° 26′ 15″, this taken from 118° leaves

$$\begin{array}{r} 118^\circ\ 0'\ 0'' \\ 53^\circ\ 26'\ 15'' \\ \hline \text{N. } 64^\circ\ 33'\ 45''\text{ W.} \end{array}$$

or about N.W.byW.$\frac{3}{4}$-W.

2. The several corrections to be applied to the apparent or compass course are—

1. Variation } Easterly is to be applied to the right.
2. Deviation } Westerly is to be applied to the left.
3. Leeway from the wind.

The courses are corrected thus:

1. N.W. or	45° 0′ 0″ l. of N.	2. S.W.$\frac{1}{2}$-W. is	50° 57′ 30″ r. of S.
Variation	19° 41′ 15″ r.	Variation...	22° 30′ 0″ l.
	25° 18′ 45″ l. of N.		28° 27′ 30″ r. of S.
Deviation	10° 0′ 0″ l.	Deviation ...	4° 30′ 0″ l.
	35° 18′ 45″ l. of N.		23° 57′ 30″ r. of S.
Leeway...	28° 7′ 30″	Leeway......	19° 41′ 15″
True C. N.	63° 26′ 15″ W.	True course S.	43° 38′ 45″ W.

3. N.	0° 0′ 0″	4. S.byE. is....	11° 15′ 0″ l. of S.
Variation	14° 3′ 45″ r.	Variation...	16° 52′ 30″ r.
	14° 3′ 45″ r. of N.		5° 37′ 30″ r. of S.
Deviation	11° 0′ 0″ r.	Deviation ...	3° 0′ 0″ r.
	25° 3′ 45″ r. of N.		8° 37′ 30″ r. of S.
True C. N.	25° 3′ 45″ E.	Leeway......	19° 41′ 15″
		True course S.	11° 3′ 45″ E.

3. The method of swinging a ship to make a deviation table is fully explained on page 18.

If the standard compass on board marks S.W.$\frac{1}{2}$-W., and that on shore N.E.byE.$\frac{1}{2}$-E., the deviation is found thus:

Invert S.W.$\frac{1}{2}$-W. it is N.E.$\frac{1}{2}$-E. (Compass bearing.)
The shore compass is N.E.byE.$\frac{1}{2}$-E. (True bearing.)
The difference is 1 point.

And because the true is to the left of the compass the deviation is 1 point W.

4. That the arc of a parallel of latitude is equal to the corresponding arc of the equator, multiplied by the cosine of the latitude, has been proved in parallel sailing, page 87, where it is shown that

$$M = L \text{ Cos. lat.}$$

5. *Departure* is the perpendicular distance between the meridian left and the meridian arrived at in nautical miles.

Nautical distance is the number of nautical miles a ship has gone in any direction.

True difference of latitude is the number of nautical miles a ship has gone due north or south.

$$\text{Departure} = \text{true diff. of lat.} \times \text{Tan. course.}$$

This is proved from previous figures.

$$\text{Tan. C.} = \frac{AF}{CF} = \frac{\text{dep.}}{\text{diff. lat.}}$$

$$\therefore \text{ dep} = \text{diff. lat.} \times \text{Tan. course.}$$

6. On pages 41-47 the log has been described, and its uses illustrated.

If the nautical mile is 6080 feet, and the glass runs out in 30 seconds, the corresponding length of knot is thus found:

As 3600 sec. : 30 sec. : : 6080 ft.

$$\begin{array}{r} 30 \\ 3600)\overline{182400}(50\tfrac{2}{3} \text{ feet.} \\ \underline{180} \\ 24 \\ \overline{36} = \tfrac{2}{3}. \end{array}$$

Ans. $50\frac{2}{3}$ feet long is the knot.

7. This is a case in parallel sailing where

$$M = L \text{ Cos. l.}$$

by question $M = 38$ miles.

" $L = 60$ miles or $1°$.

We have to find *l*.

$$\therefore \quad 38 = 60 \times \text{Cos. l.}$$

$$\therefore \text{ Cos. l.} = \frac{38}{60}$$

$$\begin{array}{l} \text{Log } 38 \ldots\ldots\ldots\ldots = 1{\cdot}579784 \\ \underline{\text{Log } 60 \ldots\ldots\ldots\ldots = 1{\cdot}778151} \\ \text{Log Cos. } 50° \, 42' = 9{\cdot}801633 \end{array}$$

Ans. The ship was in lat. 50° 42′.

8. If a ship sail from lat. 38° 4′ N., S.E. by S., till her departure is 50 miles, the distance she sailed and her latitude are found thus:

(1) Go to the traverse table, and with 3 points as a course find departure 50 in its proper column; we see that

Diff. of lat. is 74·8 and dist. 90 miles.

Latitude from is	38° 4′ 0″ N.
Diff. of latitude is	1° 14′ 48″ S.
Latitude in is.....	36° 49′ 12″ N.

(2) It may be worked thus, constructing figure on page with N S E W and triangle C D G.

$$\text{Sin. Course} = \frac{\text{G D}}{\text{C D}} = \frac{\text{departure}}{\text{distance}} \quad \text{Cos. C.} = \frac{\text{C G}}{\text{C D}} = \frac{\text{diff. lat.}}{\text{dist.}}$$

$$\therefore \text{Sin. 3 pts.} = \frac{50}{\text{dist.}}$$

∴ dis.... = 50 × Cosec. 3 pts.	∴ diff. lat. = dis. Cos. C.
Log. 50...... = 1·698970	Log. dis. .... = 1·954231
Cosec. 3 pts. = 10·255261	Cos. C. .... = 9·919846
Log. dis. 90 = 1·954231	Log. diff. lat. 74·83 = 1·874077

Latitude in is found as before.

9. To find the compass course from A to B, we must first notice the latitudes and longitudes. By examining them we find that the longitudes are the same, or the ship neither goes east nor west, while the latitudes vary, or the ship goes southwards

From	36° 18′ N.
To	13° 27′ N.
	22 51 S.
	60
Distance	1371 miles.

To find compass course—

True course is	0° 0′ 0″ N.
Variation, E.	8° 26′ 15″ l.
	8° 26′ 15″ l. of N.
Deviation, E.	4° 0′ 0″ l.
Compass course N.	12° 26′ 15″ W.

10. If a ship is in latitude 45° 18′ S., lon. 44° 25′ E., and sails W.S.W. until she is in latitude 47° 14′ S., she has gone southwards

From	45° 18′ S.
To	47° 14′ S.
	1° 56′
	60
Diff. lat.	116 miles.

With difference of latitude 116 miles, and course W.S.W., or 6 points right of S., the departure and distance, as found in the traverse tables, are

280 departure, 303 distance.

By calculation we get them thus—

$$\text{Cos. C} = \frac{\text{diff. lat.}}{\text{dist.}} \qquad \text{Sin. C} = \frac{\text{dep.}}{\text{dist.}}$$

$\therefore$ dis. = diff. lat. × Sec. C. $\qquad$ $\therefore$ dep. = dist. × Sin. C.

Log. 116.........	= 2·064458	Log. dis.......	= 2·481618
Log. Sec. 6 pts.	= 10·417160	Sin. C..........	= 9·965615
Log. dis. 303·1	= 2·481618	Log. dep. 280	= 2·447233

Ans. Dep. 280 miles; distance 303 miles.

11. We must here first find the true course from the compass course, and then the difference of latitude from which the mid-latitude can be found, with which and the departure also to be sought the difference of longitude may be obtained.

To find Course—

Compass Course....	67° 30′ 0″ r. of N.
Variation............	8° 26′ 15″ l.
	59° 3′ 45″ r. of N.
Deviation...........	8° 0′ 0″ r.
	67° 3′ 45″
Leeway, ...	11° 15′ 0′
True course, N......	55″ 48′ 45″ E.

To find diff. lat.—

$$\text{Cos. C} = \frac{\text{diff. lat.}}{\text{dist.}}$$

Log. dis. 70..........	1·845098
Cos. 55° 48′ 45″.....	9·749662
39·33 m.........	1·594760

To find dep.—

$$\text{Sin. C} = \frac{\text{dep.}}{\text{dist.}}$$

Log. 70...............	1·845098
Sin. 55° 48′ 45.....	9·917612
57·9 m..........	1·762710

Latitude.	Mid-latitude.	Longitude.
Lat. from 38° 44′ 0″ N.	38° 44′ 0″	Lon. from 18° 33′ W.
Diff. lat. 0° 39′ 19″ N.	39° 23′ 19″	Diff. lon. 1° 32′ E.
Lat. in... 39° 23′ 19″ N.	2)78° 7′ 19″	Lon. in.... 17° 1′ W.
	39° 3′ 39½″	
	90	
	51°	

With co-mid-lat. 51° as a course, we go to the traverse tables and find departure 57·9 in its proper column; opposite to it in the distance column is 92′; this is the difference of lon. 1° 32′ which we have applied to find longitude in.

12. This is a traverse, and we resolve it thus:

Courses.	Dist.	Diff. lat.		Departure.	
		N.	S.	E.	W.
S.S.E. - - - 2 pts.	30		27·7	11·5	
E.byS. - - - 7 pts.	18		3·5	17·7	
S.W.byW. - 5 pts.	36		20		29·9
W.$\frac{3}{4}$-N. - - 7$\frac{1}{4}$ pts.	14	2·1			13·8
S.E.byE.$\frac{1}{4}$-E. 5$\frac{1}{4}$ pts.	46		23·6	39·5	
		2·1	74·8	68·7	43·7
			2·1	43·7	
			72·7	25	

From the tables this corresponds to a
Course, S. 19° E.; distance, 77 miles.

Latitude.	Mid-latitude.	Longitude.
Lat. from 51° 25′ 0″ N.	51° 25′ 0″	Lon. from 8° 12′ W.
Diff. lat. 1° 12′ 42″ S.	50° 12′ 18″	Diff. lon. 0° 40′ E.
Lat. in... 50° 12′ 18″ N.	2)101° 37′ 18″	Lon. in.... 7° 32′ W.
	51°	
	90	
	39° Co-mid-lat.	

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